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THE

TRANSACTIONS

OF THE

INSTITUTION OF CIVIL ENGINEERS

OF IRELAND.

VOL. I.

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The Editor of the Transactions is directed to state, that the authors alone are responsible for the facts or opinions expressed in their several communications.

TRANSACTIONS

OF THE

INSTITUTION OF CIVIL ENGINEERS

OF IRELAND.

[November 12, 1844.[

On the ARTIFICIAL PREPARATION OF TURF, *independently of Season or Weather*, by R. MALLET, ESQ. C. E. MEM. INS. C. E. M. R. I. A., &c. &c.

OF the three principal sorts of fuel provided by the Creator for our use—timber, turf, and coal,—mankind have availed themselves in the course of time, and progress of civilization, in the inverse order of the respective ages or antiquity of these products themselves. Thus, timber has fed the earliest fires probably ever kindled by man; ready to his hand, and always growing for his use, its application to fuel has in every state long survived the dawn of civilization, until at length, the waste of forests, and their subjugation by advancing agriculture, together with the adaptation of timber to naval and civil architecture, and a multitude of other arts, has made it too valuable to be longer burnt.

Peat, wherever it abounds, has formed the fuel of the middle age of man, in arts and social progress. Thus, an ancient author, speaking of the Batavi as reduced to drink beer, and burn turf, says : "O miseram gentem quæ cibum suum bibit, et terram suam urit;" and later, Cardinal Piccolomini, afterwards Pope Pius II. writing in

1458, of Frisia or Friesland, says, "ligno caret bituminoso cespite ignes fovent."

Coal, like the wondrous powers which its extended use has enabled the genius of man to develope, is comparatively a thing of yesterday—the commencement of its general use for fuel, scarce reaches back to the wars of the Rival Roses. Its domestic use was discouraged in the reign of Elizabeth ; and the dawn of the last century only witnessed the first great application to arts and manufactures of the fossil fuel, which the invention of Newcomen's engine, had then enabled to be raised abundantly.

The natural gifts of sovereign goodness, however, are distributed with a discriminative hand, that man, in His image, and in the likeness of His power, may ever exercise the creative energies with which he has been endowed, and that his course may be ever onwards.

And thus it is, that in countries such as Ireland, almost deprived of fossil fuel, improvements in the preparation and use of Peat, which so abounds, should always be an object of solicitude. Accordingly, though little regarded here, and commonly viewed as only worthy the attention of the peasant, whose winter comforts depend so much upon its collection, the best method of preparing, and using Turf, have long formed objects of even national investigation, in continental countries possessing extensive deposits of Peat: and in the languages of Denmark, Holland, Germany, and France, an extensive, though little known, literature of the subject exists. With us attention to the improvement of Peat fuel has been rare and casual, and confined to a few individuals, whose energies have unfortunately taken a wrong direction, so that, in fact, the actual practice of collecting and preparing this, the national fuel of Ireland, has always remained unimproved, and is now in its most primitive condition.

To point out what is the direction and aim with which improvement in the collection and preparation of Peat fuel must be sought, and to describe some methods in successful practice in foreign countries, together with some new apparatus which I have devised for the preparation of Turf, independently of season or weather, form the principal objects of this communication. It will be necessary, preliminarily, to notice briefly other proposals made at various times, for the improvement or use of Peat fuel, and to point out the reasons of their partial or entire failure.

To treat this subject fully, it would be desirable to discuss the geological relations of Peat, and the theories that have from time to time, been formed as to the origin and growth of bogs—as this would, however, exceed the limits of this communication, and the proper objects of this Institution, I will only remark that, the commonly received notion that Bogs have been produced by the gradual drainage and filling up by growth with vegetable matter, of shallow lakes, appears quite inadequate to account for the phenomena observable, in the Peat formation; for as such, namely, as the very latest of formations, must the deposit of flat and mountain bog in all countries be viewed.

To render this account, which has received the sanction of the Irish Bog Commissioners, of Portlock, and others, tenable—some distinct origin must be found for the decay of the primary mass of vegetable matter, up to the peculiar state of Peat, and no further—which origin the received view does not supply. Shallow lakes overgrown with aquatic plants and mosses, are observable daily in course of drainage and filling up, but, no true Peat bog, that I am aware of, can be pointed out in act of forming.

Wherever Peat is found in growth, Peat has already existed and conferred upon fresh vegetable matter, brought into contact with it, that peculiar form and tendency of decay and decomposition which ends in Peat, and there stops; a form of decay, that might, with propriety, be called the Peaty fermentation, the last result of which is a product of singular chemical stability. A clear conception of the forces, physical, geological, and chemical, concurring to produce this form of decay, in which, as I believe, the true origin of the bog formation is to be found, must be of the greatest value to those whose objects in the treatment of peat is to render it of value in agriculture. This I must reserve for other occasions; it will be useful here, however, to fix our ideas as to the ultimate constitution of peat, and of the substances from which it is derived, or that are derivable from it, or rather of the types of these bodies; for peat, as found in nature, contains in various localities, a variety of foreign substances, the presence of which has caused the accounts of authors treating of Peat as a body of invariable constitution, often to be contradictory. Thus, Mr. C. W. Williams, speaking of Irish peat, recommends its charcoal for use in manufacturing iron, on the grounds of its containing no sulphur. This is not quite true even of Irish peat, but it is much more nearly so, than it would be in respect of some Scotch and French peats; some of the latter are so rich in minutely divided sulphates of lime and Iron, as to be actually used for alum making. Again it has been stated by many authors, that the dry distillation of peat in the process of draining, produces no ammonia, the peat containing no nitrogen (Kane); while others have described and identified the ammoniacal liquor so obtained (Pfeiffer): the fact being that some sorts of

peat are almost destitute of nitrogen, while others, as for instance the Dutch bogs, are rich in this constituent.

In the examination of peat too, chemists have been incautious as to the nature and amount of ashes; results taken from specimens removed from close, or nearly close to the bottom of bogs, are always erroneous, the composition of ashes due to the natural inorganic constituents of the plants, from which the peat has been formed, being for some feet from the bottom always perplexed, and the apparent quantity increased, by solid matter derived from the bed on which the bog rests.

In speaking of the ashes of peat, it may be observed, that the supposed value of the upper or red turf for charring, founded upon the idea of its entire freedom from sulphur, (Williams) rests upon a chemical mistake. One of the principal inorganic constituents of the plants, which now principally cover our bogs, and which in decay, constitute the red bog, is sulphate of lime. The charcoal from the red or any other bog, can therefore never be free from sulphur—indeed a fact often remarked as difficult of explanation, viz: the spontaneous growth of white clover, wherever a patch of surface bog has been burnt, appears to be owing simply to this circumstance. The ashes of white clover itself abound in sulphate of lime, and in accordance with the general law, the seeds of the plant carried by birds or sheep, &c., grow and thrive where they find their most important inorganic constituent thus liberally supplied them.

If in this view I am correct, the hint afforded to the agriculturist for thus improving the surface of bog, may not be lost.

Air, water, and the alkaline reaction of water charged with Lime or some saline matters, are essential to the

peaty fermentation ; certain limits as to temperature are also indispensable.

The ultimate constitution of wood fibre, the type of all vegetable tissues, is

$$C_{36} \quad H_{22} \quad O_{22}$$

When this oxidates in damp air, for every two atoms of Hydrogen formed into water, one atom of Carbonic acid is formed and set free ; the result is

$$\begin{array}{ccc} C_{36} & H_{22} & O_{22} \\ C & H_{2} & O_{2} \\ \hline C_{35} & H_{20} & O_{20} \end{array}$$

which is the formula of rotted wood—and the composition which ancient drift wood generally shows.

But if the vegetable fibre be secluded from air, and freely supplied with aerated water—water enters into the composition, and the results are either

White rotted wood,... ... $C_{33} \quad H_{25} \quad O_{24}$

or Lignite, ... $C_{33} \quad H_{21} \quad O_{16}$

that is to say, wood fibre minus

$$H + 3\,C\,O_{2}$$

according as the pressure of water has been more or less abundant, and other circumstances have varied.

In some peat, ammonia is also formed as well as water. Thus Dutch peat from Haarlem and Friesland, had the following constitution

Haarlem, $C_{40} \quad H_{24} \quad O_{12} \quad N_{2} \quad H_{6} \quad 4\,H\,O$

Friesland, $C_{40} \quad H_{24} \quad O_{12} \quad N_{2} \quad H_{6} \quad 5\,H\,O$

which is humic acid with 4 & 5 atoms of water and ammonia.

Peat, although an organic substance of singular chemical stability, is still not absolutely stable. A slow but constant change takes place, dependant upon temperature, pressure, and supply of aerated water, by which the proportion of its constituents constantly change, and it approximates more and more to coal, so that there is gradually removed from the original vegetable fibre:

3 Atoms Carburetted Hydrogen = $C_3 H_6$ —

3 Atoms Water..... = — $H_3 O_3$

9 Atoms Carbonic Acid..... = $C_9 O_{18}$

$C_{12} H_9 O_{21}$

deducting these from the original fibre

$C_{36} H_{22} O_{22}$

$C_{12} H_9 O_{21}$

There remains $C_{24} H_{13} O$ splent or cannel coal; and by a further change, due to increased temperature, more carbon and hydrogen are removed, and caking coal, $C_{20} H_9 O$ results, being cannel, minus olefiant gas, $C_4 H_4$ The last result, and which completes the cycle of change, is anthracite, which is almost pure carbon.

These results, to which we shall have occasion hereafter to refer, are chiefly due to the labours of Leibig, Richardson, and Mulder.

The earliest treatise upon the preparation and use of peat fuel that I can find any notice of, is one added by Guicchardin to his History of Holland, where, as early

as the beginning of the sixteenth century, it had become an important fuel, for the state of Overyssel petitioned Charles V., at his coronation in the year 1528, to prevent the export of their turf, so valuable did they then esteem it.

Martin Schookius, Professor of Philosophy at Groningen, published some time after, a work, "De Turfis seu de cespitibus bituminosis." This book, although now forgotten and scarcely known, was for a length of time the great authority with the learned of Europe as to the nature and origin of bog, and all that relates to the economy of turf.

From an old German book on Metallurgy, published at Altenburg, in 1781, I find that turf was used for metallurgical purposes in Saxony as early as 1560, but whether raw or charred is uncertain.

The inventor of charring turf (certainly in France), was Charles de Lamberville, avoçat and consul, as he himself states in his "Discours Politiques et Economiques," of which a second edition (the only one I have seen), was published in 1631. He was obviously a man of genius, education, and enterprise much beyond his age. He brought workmen and tools from the bogs of Denmark and Holland to work those of France which had before lain wholly useless, and the very existence of which in many of the provinces he first pointed out. He describes his method of charring, which consisted in burning a large heap of turf sods, covered with earth and "stiffling out," a method which has been very lately recommended as the best possible, but which the author himself candidly states did not answer, the great falling in of the turf heap by loss of volume in burning, causing the earth covering to get perpetually broken, and thus the

stiffling unsuccessful, and the labour of attendance too costly, as well as waste of turf and incomplete carbonization. He tells us that he applied his turf charcoal to forging and welding iron in horse-shoes, keys, &c., and in a variety of other trades. A sudden death removed this able and ingenious man in the midst of his labours.

Charles Patin, who published a Treatise on Turf, in 1663, which received the imprimatur of approbation from the Sorbonne, alludes to the labours of Lamberville, though not by name, and gives a curious anecdote, which shows how novel was then the use of peat fuel in France, namely, that an immense stack of dry turf, prepared by him near Essonne, was burnt by the peasants making a fire (of wood it is to be supposed) against the stack, ignorant of its inflammability.

Dietrich, in 1781, describes certain kilns or carbonizing furnaces for turf which he had seen in operation in the Hartz. He says they were large cylinders of cast iron, into which the turf was thrown, lighted from beneath at certain apertures capable of being closed, and "stiffled" at top with earth or clay when the combustion had proceeded sufficiently far; in fact these ancient kilns are almost identical in construction with those recently proposed and patented by Mr. C. W. Williams. Dietrich says, the bulk of turf charcoal obtained was one-half that of the turf, or 52 cubic feet, from 3,000 sods of turf. For smiths' work, he says, the charred turf will answer, but that it requires one-third more fuel for an equal amount of work than when charcoal of wood is used, and that it is so light it will not bear the blast, but is blown away in dust and fragments. To which I may add that experiments made more recently in the ateliers of the Hotel des Invalides at Paris, on the forging of gun-

barrels with char-turf, gave as results, twice the consumption of the fuel and twice the time occupied by the best workmen in doing a given amount of work, as compared with the use of charcoal.

Many old German and Dutch authors on Metallurgy, I find, describe those kilns for charring turf, as Lehman, Cramer, Schreiber, Becher, and Boerhaave. Mr. Boyle also seems to have devoted some attention to the subject.

Guettard, in 1761, describes kilns as in use at Villeroi in France, of a form like the modern Vichy lime-kiln, viz., a large inverted cone of masonry, with apertures below for kindling the mass which was stiffled above with earth—these kilns were of large size.

In 1777, Pfeiffer, a German author on turf, minutely describes the process of carbonization *in close vessels*, or retorts, and distinguishes the several products of tar, oil, phlegm, *i.e.* ammoniacal or acid liquor, &c. ; and in 1787, a M. Fremin obtained an exclusive privilege from the king for the use of this process in France. He appears to have used large retorts made of hammered plate iron for his carbonization.

In the same year Carnolle describes in the *Journal des Scavans*, another sort of kiln, a cylinder of masonry of 15 feet diameter by 3½ in length, with a grating over the whole bottom which was flat, the grate sustained by brick blocks ; upon the grate the turf was thrown and piled in a cone above the top of the kiln, and then covered with earth. The fire was kindled at apertures in the sides on the level of the grate, these were gradually stopped as the charring proceeded, and finally the "stiffling" was completed with earth on top. The cone of turf was covered with wet straw before the earth was overlaid. Thirty measures of turf, he says, give twenty

of char-turf, sometimes only fifteen. This arrangement must have been subject to all the evils of Lamberville's original plan.

In 1791, Ribancourt and Le Sage record some experiments on the charring of turf, and for the first time, the pyrophoric property of char-turf, or its tendency when fresh made to spontaneous combustion, is noticed. They attribute this to the presence of sulphur, and notice the sulphurous smell exhaled by throwing water upon the fresh char-turf. This property, which is so troublesome in practice, is now known to depend upon a different cause.

In 1786, Le Sage published in the *Journal de Physique*, some most erroneous experiments upon the comparative heating powers or values, as fuel, of char-turf and charcoal of wood. According to him the former gives three times a greater result in heating water than the latter. These specious conclusions gave an immense but transient impetus to turf-charring in France

It is easy to see, on carefully examining the nature of Le Sage's experiments, how they are erroneous, and by what he deceived himself; his apparatus was such that nearly the whole of the heat evolved from the *slow* burning char-turf was absorbed by the vessel of water, but the draft was such, in the case of the more rapidly combustible wood charcoal with which he compared it, that a large portion, indeed by far the largest portion, of the heat evolved from the latter, passed off and was lost. The necessities of revolutionary France, and the scarcity of fuel soon after, induced administrative exertions to be made in favour of turf as a substitute for wood, and Le Sage's mistaken views became highly popular.

In 1792, M. Thorin improved the apparatus for car-

bonization in close vessels, and upon a report addressed to the Academy of Sciences, by Berthollet and Le Blanc, he received a national reward of two thousand livres. By his process he saved all the products of the carbonization except the gases evolved. The report states that 95 measures of turf produce 65 of char-turf, with a consumption beneath the retort to heat it of 67 more measures of turf, so that in fact 162 measures of turf were required to produce 65 measures of char-turf along with 17lbs. of tar, 5lbs. of oil, 9 pails *(sceaux)* of ammoniacal liquor, and 10 bushels of ashes for manure. The iron retorts were rapidly destroyed in the process, no doubt principally by the action of the water and sulphate of ammonia upon the metal.

M. Thorin's char-turf was tried by the reporters and found to answer for forging the blades of penknives or such like light articles, but for forging heavier work they speak of it very doubtfully.

The reporters mention, on the authority of Doctor Alex. Lind, that trials had been long before made in Scotland to work metals with char-turf, but had all failed; that "something was in it which produced the same effects as sulphur upon iron;" that "for smelting operations the slag was troublesome, &c."

Blavier, in the year III. of the French Republic, states that he was able to obtain from 55 to 60 measures of char-turf from 100 measures of turf from the banks of the Essonne.

In 1805, Platel described in the *Annales de Chimie*, some very ingenious apparatus for carbonizing turf in close vessels, in which the inflammable gases given off are burnt under the carbonizing retort, and thus a great economy of fuel produced. He appears to have carried

the preparation and carbonization of turf quite as far and with as well designed apparatus as any one who has succeeded him.

He first pressed the turf wet, by an equable and continuous pressure to remove water, then air-dried and carbonized it. The char-turf he produced, he says, had a greater specific gravity than wood charcoal. He notices accurately the occurrence of nitrogen in the peat, ammoniacal salts in the distilled liquor, and of sulphur from the sulphate of iron contained in the peat. He also proposed to use the waste heat of the smoke from his retort, when not in a condition to be burnt, as a means of partially dessicating the turf prior to its carbonization. He says five or six parts of his turf are equal to four of wood. The turf he employed produced from 100 parts, 38 to 42 parts of char-turf, which produced, on incineration, from 13 to 16 parts per cent. of ashes. Three parts of this char-turf, and one part of briskly burning wood, will, he found, answer for burning bricks or pottery. Most of the peat he used, appears to have yielded no ammonia, but only acetic acid which he employed in making verdigris. This intelligent manufacturer gives his decided approbation to the Dutch method of extracting and preparing turf for drying, a method of which we shall have more to say anon.

Both raw turf and char-turf have been tried abroad in the blast furnace for smelting iron, but with ill-success. Datzl, Reuss, Lampadius, and other German Metallurgists, speak in terms of praise and approbation of this use of raw turf. None of them seem, however, to have tried it except Lampadius, and he seems only to have made a single experiment for Count Sternberg, at Radnitz.

Wagner, however, gives the detail of his experiments made on the use of raw turf in the iron furnaces of Bergen in Bavaria—(Annalen der Berg und Huttenkind, Band. 1. 1801). The raw turf, cut into small pieces, was mixed with charcoal in proportions varying from one-seventh up to one-fourth. The results were not favourable either as to the yield or quality of the iron—the ore was lenticular clay ironstone. If half turf and half charcoal was used, the iron made were all quite white. The turf was only air-dried, and therefore still really very moist, and to this he attributes the failure.

Other trials made in the Tyrol, and reported on by Daubuisson, showed, as a final result, that the employment of char-turf mixed with charcoal, produced no economy of the latter, diminished the yield of iron, and deteriorated its quality, and that raw turf was in these respects still more disadvantageous—air-dried turf is here spoken of—(Annalen der Berg, &c. Band. IV.)

I have thus brought down the history of the preparation of turf nearly to the present day, with the view of affording a future index to persons interested in this subject, the literature of which is very little known, and more particularly for the purpose of indicating that the two great specifics for the improved use of turf, which have formed the staple of almost all recent inventors and writers upon the subject, are neither recommended by novelty nor by any past success.

The compression and the charring of turf have both been tried centuries ago, for the first time; they have been repeatedly recurred to by ingenious and competent experimentalists, and as often abandoned, after careful and lengthened trial,—the first as involving an expenditure in labour, which the result does not repay, and as ex-

pressing from the fibrous mass of the wet turf, suspended in the water, some of the most valuable part of the fuel, which is thus lost: the second as replete with difficulty in the process of charring and cooling, and in result rendering a fuel which, in its natural *dry* state, has many useful properties, almost valueless for any purpose, and dissipating uselessly the whole gaseous part of the turf, which constitutes so important a fraction of the whole fuel.

Whatever has been long tried by a number of different skilful persons, whose interest has been in success, and which, after all, has dropped through and failed of any extended or practical use, may fairly be concluded to possess inherent and real grounds of failure; and unless to one enamoured of a single idea, it is only necessary to see and handle a bit of the best made char-turf to know what these grounds are. The substance, though possibly of equal specific gravity with wood charcoal, is yet so friable that it will neither bear carriage nor handling, after the difficulties of its manufacture have been overcome. When burnt with a draft, it does not ignite at once throughout its whole mass, as charcoal does, but eats away as it were from the outside alone. If used with a blast, it is blown away in fragments or dust. The difficulties of using it for forging iron are known to every horse-shoer in the north of Ireland, where, in remote districts, it has long formed his fuel. By far the larger part of the useful heating power of turf is dissipated and lost by charring it. Pit coal, when coked, loses about 25 per cent. in weight, and leaves about 75 per cent. of hard workable coke. Dry turf, on the contrary, when charred, loses about 75 per cent. of its whole weight, dissipated as inflammable gases chiefly, and leaves but 25 per cent. of char-turf, just reversing the proportion with pit coal. It

is at once apparent that, unless some most valuable and important new qualities are conferred on the one-fourth which remains of the original fuel by charring, this loss of substance must be prohibitory to the economy of the process; but no such properties are conferred.

Unless, therefore, some altogether inconceivable improvement be effected in the pressing and charring of turf, these processes ought hereafter to be viewed as trials made, repeated, and justly abandoned as unfit methods for increasing the value of turf fuel, for general purposes, and on the large scale. I omit any consideration of the numberless inventions, patent or otherwise, for making what are called "artificial fuels," whether by grinding turf and coal or turf and limestone, or "saw dust, or other refuse, with coal tar," or such like, the best proof of the inutility of attempting to compete with nature, in *making coal* by any such crude devices, being their successive abandonment by their own sanguine inventors.

Laying aside all these, therefore, I shall endeavour to show that turf-making is susceptible in this country of great improvement. 1st—In the mode of its collection or isolation from the bog. 2d—In the mode of its preparation.

The former viz. improvement in collection will consist in the extensive adoption of the Dutch method of turf-making, in place of cutting in sods, as generally practised in Ireland; the latter in thoroughly drying the turf when so made, in suitably constructed kilns, heated by refuse turf, or turf mould. These methods I shall proceed to develope, but as the latter (kiln drying) may be practised without the former, and in concert with the existing modes of turf cutting, I shall describe it first. In doing so I will have occasion to bring before the Institution information partly original, and partly derived from observation of the practices of foreign nations.

For several years past turf has been extensively used for re-melting pig iron, and for the puddling and balling processes in many of the German iron works. The only preparation to which it is subjected, consists in drying it thoroughly by artificial heat, in peculiarly constructed kilns. It has been most successfully and largely used at Känigsbrunn, in Wurtemberg, where the idea of substituting turf for wood, as fuel for the reverberatory furnaces, first occurred to Mr. Weberling, the director of works, in 1833. The turf is dug from a great number of turbaries, covering the great jurassic plain of L'Albe, at about three leagues from Heidenheim ; it is of excellent quality, dark brown in colour, containing very little unaltered organic matter, and a very small proportion of ashes, which consist principally of carbonate of lime.

The turf is dug in sods about the size of large bricks ; these remain drying in the air, spread and piled, much in the way usual in Ireland, for about six weeks before being brought to the works; thus imperfectly dried, it bears carriage, and in dry weather even feels dry to the touch ; but it is far from being dry enough either to produce a high temperature in the furnace, or leave the iron uninjured. Various trials were at first made to improve it by compression, which proved abortive and useless ; it was a most expensive process, did not answer the end of drying, and wasted much of the fuel. Pressing was, therefore, abandoned, and the method of drying or desiccating by artificial heat in a kiln or oven substituted. The temperature of the oven is about 100° cent^{r}. or 212° Fah^{t}.

Plate I. Figs. 6 and 7 are a plan and section of this kiln. Fig. 6 is a vertical section through A B. Fig. 7, a horizontal section and plan on the level of C D. The same

letters refer to both. *a* is the chamber or body of the kiln, covered above by the ceiling of iron plates, *n*, and with a slated or tiled roof, *o*. The chamber is surrounded with brick walls, one of which is full of apertures, *l*, *l*, and divides it from a second or hot air chamber, *p*, whose temperature is raised by the radiated heat from the cast iron flue, *f f*. The damp turf is thrown into the chamber, *a*, by the iron door, *h*, and piled loosely and promiscuously until it completely fills it. It rests upon or is supported by an open wooden grating or floor, resting on iron spars, built into the side walls, at about nine inches above the cast iron plates, *c*, which form the bottom of the chamber. *d* is the fire-place or furnace, in which the refuse "brize" or broken charcoal of the works, or turf dust, is burnt. The flue, *e e′ e″ e‴ e⁗* from this passes back and forwards, beneath the plates, *c*, which become strongly heated, and are the media by which heat is communicated to the chamber, *a*. The hot air and gases of the fire, after passing through this flue, continue through the cast iron flue pipe, *f f*, and finally are discharged into the stalk *g*. A number of cold air apertures are formed at *k k*, above the level of the flue-plates, *c*, but below the level of the grated floor, *b*, and at the level of the upper part of the chamber two other exit apertures, for warm and moist air, are provided through the back external wall, at *m m*.

When the chamber has been filled with damp turf, and the door, *h*, again secured, and the plates, *c*, become heated by the fire beneath, a slow but constant current of warm dry air is kept passing upwards through the mass, passing outwards through the apertures, *l l*, and, carrying off the moisture of the turf in its progress, is discharged loaded therewith at the aperture, *m m*. As soon as a cold plate

of iron held to these, does not become moistened, the turf within is dry. The door, *h*, is then taken down, and the turf thrown out for use.

The chamber of the kiln holds 11,500 sods of turf, and one charge requires for complete desiccation a period of from 9 to 10 days. The process cannot be hastened by raising the temperature of the kiln above 212° or 250° faht. at most, as the turf, when completely dry, takes fire like "amadou," at a little higher temperature, and burns.

One thousand sods of turf cost at the bog 53 kreutzers = 1.74 francs = 1s. 5½d. British, nearly. Their carriage to the works costs 2 florins = 4.18 francs = 3s. 6d. British, nearly. One hundred and thirty sods of turf, air dried at the bog, weigh about 1 quintal (Wurtemberg) = 43.63 kilograms, or one thousand sods weigh 335.61 kilograms = 738½lbs. avoir. A cubic foot weighs about 14lbs.* Berthier has given an analysis of this turf (Ann. de Chim. 1835). He states its composition to be—

Carbon, ..	24.4
Ashes, ..	5.0
Volatile matter,	70.6
	100.0

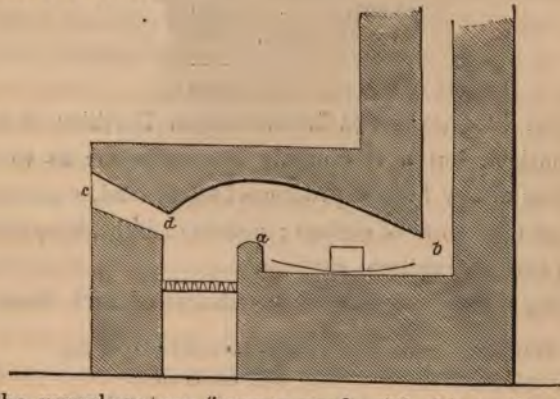
With the litharge test (a favourite with Berthier, it may be remarked, but a thoroughly fallacious one as to the real value of any fuel) it produces 14.3 of lead, equivalent to 43 per cent. total of carbon; although light, it is, therefore, a turf of excellent quality.

During the kiln drying of one charge of turf, there is

* The Würtemberg foot = 0.287 metres, = 0.983 feet, British.
The ,, cubic foot = 0.03445 cubic metres cubic.
The Zuber..... = 20 Würtemberg feet, = 0.689 cubic metres.
The Quintal ..... = 95.98 lbs. avoirdupois.
The Stere ..... = 1 cubic metre = 35.317 cubic feet, British.

burnt of fuel, for heating the kiln, 4 zubers = 80 cubic feet (Wurtemberg) = 2.757 cubic metres = 3 cubic yards British, nearly, consisting of the refuse charcoal dust and turf mould; and as the oven holds from 650 to 700 cubic feet of turf (Wurtemberg), the desiccation requires from $\frac{1}{9}$ to $\frac{1}{8}$ of the bulk of turf dried, to free it from moisture. This refuse fuel, however, is almost valueless.

In other words, 1 cubic yard of turf-mould and charcoal dust will dry in this kiln from 8 to 9 cubic yards of turf. *The turf, thus desiccated, loses nearly one-half of its weight when air dried only*, 30 quintals being reduced in weight to 18 quintals, thus losing 40 per cent. of moisture. *The sods diminish in bulk to about one-half their former volume, and acquire great compactness*, thus answering all the ends obtained by compression; they are greedy in regaining moisture (up to a certain point, but in no length of time under cover will they regain the whole that they have lost), and as in these works the object is to obtain the highest possible temperature, the turf is used nearly as fast as it is dried.



The reverberatory furnace used with this turf is 8 feet long in the bed, *a b*, and 3 feet across the bridge. The

grate is 36 inches wide, and placed at 18 inches below the bridge. The small size of the fire-place here will indicate the power of the fuel. Where wood was used, it was found that the section of the throat above the bridge should be to that of the grate, as 1 : 13, but when the dried turf is burnt it is found desirable to make it, as 1 : 7.

The stalk is 66 feet in height, and the furnace will melt 40 quintals (Wurtemberg) of pig iron in five hours. The turf burns so fast that the process of charging is almost incessant, (this is the case even with steam boiler furnaces, fired with turf, in this country,) and for facilitating this, there are two inclined openings, *c d*, through which the turf is thrown in, and which are kept closed with turf sods.

The loss of iron in fusion with this furnace was 7.8 per cent. with wood, and is only 5.9 per cent. with dried turf—this arises from the increased rapidity of melting with the desiccated fuel.

The quintal of cast iron requires 176 sods of turf to melt it; it formerly required 9.3 cubic feet of wood to do so; thus a cubic foot of wood is equivalent to 18 or 19 sods of turf, or to about 2¼ cubic feet of desiccated turf—which is 550.10 sods of turf = 1 stere of wood.

Few trials have as yet been made for using this desiccated turf in the smelting furnaces; but the use of scorched or baked *wood*, in place of charcoal, for the blast furnaces, is becoming general throughout Germany.

Trials have been made in the "Landes," which prove that dried turf will answer perfectly for puddling and balling furnaces. It is not very likely, however, that turf in any form, can ever be very usefully or successfully used for smelting in the blast furnace, as in any state, whether raw, desiccated, or charred, it is not hard enough to

"bear the burden,"* and though all other objections were got rid of, this seems insuperable.

It is quite true that small quantities of charred turf have latterly been used, mixed with charcoal of wood, in a few of the German iron works; but it is found that the quality of the iron is deteriorated in proportion as the amount of char-turf is increased. This proportion has never been able to be increased beyond one-half that of the charcoal, and even if no deterioration of the iron resulted, char-turf could not possibly be used alone, for the reason above given, viz.: it will not "bear the burden." An abundant supply of wood charcoal is therefore indispensable to make use of char-turf, any where for iron making, hence, it is impracticable, and probably always will be, to make iron in Ireland by the aid of turf fuel. The necessity of this *co-existence* of charcoal and char turf, for such a purpose, appears to have entirely escaped Doctor Kane, in his work on the Industrial Resources of Ireland, p. 153, &c. yet upon this circumstance rests the whole difference between apparent correctness, and the actual fallacy of all the money calculations there given as to iron-making with turf in Ireland.

I have here entered into some detail in the applications of this fuel to iron works, not quite within the scope of my subject, but which I have thought it not unprofitable to notice, in order that iron founders in Ireland may know that turf, if rightly prepared, is capable of becoming a good, and in certain localities, a profitable substitute for pit coal, in large meltings *with the air furnace;* and that on the other hand, capital and energy may not be wasted in Ireland, in impracticable attempts to make iron with

* "Bearing the burden," technically means the ability to sustain the load of ore and flux in the furnace, without crushing down and choking the Blast.

turf *alone* in any state, which although so much commended by those whose scientific attainments deserve respect, but whose practical knowledge we may be permitted to doubt, has been long since, after trial, found impossible by men of science and of practice actually engaged in iron making, and whose interests would have been served in the highest degree by their success.

The kiln above described, though compact and answering its purpose well, is by no means the best calculated to economise fuel in heating, or capital in its construction, and I purpose next describing the arrangement of kiln which I have devised, and would recommend for general adoption in pushing the principle of artificial drying of turf to the full extent of substituting it in all cases for the present mode of air drying on the surface of the bog, the advantages of which will be hereafter pointed out more fully. The kiln I propose consists generally of a large horizontal flue, or prolonged chamber, through which a slow but constant draft of heated and dried air, gases, &c., passes from one or more fires, placed at one end, and fed with turf mould or such other refuse bog fuel, and finally is discharged at the other end through one or more vertical chimneys or stalks, to whose height the draft is due. The turf, damp from the bog, or at most only as much air dried as will permit of its carriage, is piled loosely upon the flat open bottom frames of light trucks, or four-wheeled railway waggons, which are fitted to run upon a light railway laid down and passing through the whole length of the warm chamber or kiln. The wet turf so placed passes into the kiln, at the cooler or chimney end, and as the waggon loads are successively dried, they pass out at the warmer

or fire-place end in succession, and their place is supplied by fresh masses of wet turf at the remote end.

Both ends of the kiln are closed, when in use, by common wooden folding-gates, and the draft from the fire passes through another pair of inner gates, formed of wire gauze upon an iron frame, before entering the chamber of turf; by this means all sparks of fire are arrested, and danger of firing the highly dried turf avoided.

Plate II., figures 1 to 6 inclusive, represent the construction of this kiln in plan, sections, &c., &c.; the same letters refer to all the figures.

Figure 1 is a longitudinal section of the kiln, and figure 2, a plan and horizontal section in a plane just above the level of the fire grates, *f f*. *a a*, the chamber of the kiln, or long horizontal flue, whose section is here shown, 8 feet wide and 8 feet high, by 100 feet in length. This is the size I would propose for the largest class of kiln, but the dimensions may be limited to suit the circumstances of locality, demand for fuel, &c. The walls of the flue, *b b*, are of rubble masonry, battered outside, and of suitable mass to carry the 4 inch brick arch, *l l*, which, with a versed sine of 12 inches, forms the roof, or rather ceiling of the flue, thus fire proof throughout. The arch may be prevented from spreading, with less scantling on the side walls, by inserting a few wrought-iron tye bars across at the level of the soffit, at intervals of about 5 feet. *c* is the pair of wood folding-gates, at the fire-place end; *d*, those at the chimney or stalk end. These gates open and close at bottom, over the top of the rails, *s s*, and when shut, the space thus remaining between them and the surface of the ground is closed by a few shovels-full of turf mould. These gates may be battened together of 1¼ inch dry memel, rebated. The frames are also of memel,

about 6 inches by 4 inches, built into the masonry; the hinges of iron, in the usual way, with an iron bolt to fasten when closed. *e e*, are the two fire-places, one at either side, for heating the kiln. Turf mould, and the top tussocks of the bog are burnt in these, which do not require much draft. A large mass is best ignited together; hence but a small portion of the bottom of these fire-places consists of fire bars, *f f*. The fuel is prevented falling forward into the kiln, on raking the fires by the grates, at *k k*. *g g*, are the front dead plates; *h h*, the ash-pits. The draft to these fires is capable of being wholly shut out by close iron fire-doors, *q q*, (figures 4 and 5) to the fire-places and ash-pits. *v* is the pair of copper wire gauze doors upon iron frames, to prevent the passage of sparks, &c., as these doors are required to form a close joint at the level of the ceiling of the kiln, the roof is here formed, not by the continuation of the 4 inch brick arch across, but by 4 inch brick dropped in on the flat, between light cast iron spars, (like common corn kiln spars), at 9 inches apart. The ceiling at *m*, is, therefore, quite flat. When the wire gauze doors are in the closed position shown in figures 1 and 2, they form a perforated diaphragm right across the kiln. They are opened back towards *k k*, to permit each waggon of dried turf to pass out, but as in this transit the dry turf must pass the mouths of the fire-places at *k k*, it is necessary at this moment to prevent any access of flame or sparks to the turf also. Accordingly the wire gauze gates are hung in such a position that, when open, they lay back against the mouths of the fire-places, where these open into the kiln, at *k k*, and thus, for the time, protect the waggon of dry turf from the fire during its passage out. In order to economise heat, and protect the 4 inch covering arch, *l l*, from the weather, rain, &c., a slated

roof, or one of tiles, or other construction, such as may most cheaply suit the locality, is placed above it, *n n*, leaving a space for air between the crown of the arch and the roof.

o o, are the two chimneys or stalks. *p p*, the out-draft apertures into them at the kiln, at the level of the floor, in order to take off the coolest, and densest, and dampest air first. These two chimney flues may unite into one above the arch roof if preferred, but if built of rubble work, two separate stalks will be most convenient; they are 4 feet square each in the clear, and 25 feet in height; at the foot of each, outside, is provided a small opening or tunnel, *r r*, to serve as a fire-place for kindling a little dry turf in at first, to produce and establish the draft. These apertures are then stopped with a few shovels-full of turf mould.

The gates at the end, *d*, are constructed in all respects like *c*, both open outwards, and fold quite back out of the way. *s s* is the railway, an edge rail of about 14lbs. to the yard will be quite sufficient, laid on larch cross sleepers. The kiln, if of the large size here shown, should be constructed not on the bog, but on firm ground close to it, on its average level, and with regard to easy carriage, of which more hereafter. The rails may continue out, to the place of bog cutting, so that the waggons may be loaded on the spot and at once transferred to the kiln. If the kiln is built on firm limestone gravel, no deep foundation will be required, and this will be the case in most parts of Ireland. The turf waggons, as they come out of the kiln, dry, may be either passed at once to the turf rick upon a temporary railway, or the turf transferred to carts for the same purpose.

t t, are the waggons of turf. The perforated bottom

frame is contrived so as to permit but a small part of the draft of the kiln to pass underneath the bottom frame or wood grating; and as the bulk of the turf on each waggon, when piled, is so guaged as to completely fill the whole cross section of the kiln, with only a clearance of three or four inches at each side and on top, the draft of heated air is compelled to pass through all the interstices of the turf, and thus to dry it rapidly. *w w w*, are three small lateral doors, about two feet square each, provided to get at the turf at various points from the fire towards the chimney, and so as to ascertain at any moment the progress of drying without withdrawing the waggons.

Figure 3, is an end elevation of the kiln at the end *c*, next the fire-places, showing the exterior of the gates, &c. Figure 4 is a transverse section of the kiln, through the centre of the fire-places, *e e*. It shows the flat brick ceiling at *m*, under which the tops of the wire gauze doors move, when opening and shutting. Figure 5, is an elevation of one of the fire-places, with side elevation of part of the kiln exteriorly. Figure 6, is a transverse section of the kiln about the middle of its length.

I trust I have succeeded in making the general construction of the kiln thus clear. A continual current of warm dry air passes into it from the fire places—travels along its whole length, carrying off from the turf the complement of moisture due to its temperature and dryness, and discharges all out through the two stalks.

The wet turf is placed first in the kiln at the cooler and damper end, and is gradually transferred along towards the hotter and dryer end, as its own drying proceeds, and is at last discharged out of the other end in a state of complete desiccation.

The true principles of rapid and complete drying are here fully brought into play—namely, a free current of dry air perpetually renewed, and the dryest material brought into contact with the dryest air; while the less dry air, thus moistened, is still used to dry the damper turf.

The gates are open when a waggon of dry turf is discharging at the end *c*, and all the waggons being pushed forward the length of one—a fresh waggon of wet turf is at the same time introduced at the end *d*; at this period the doors, *q*, of the fire places are closed, and the wire gauze doors opened back against *k k*. As soon as the dry waggon, or more than one are taken out, and the wet waggons are put in, the gates are closed. The wire gauze doors being previously shut—the fire place doors, *q*, are opened, and the kiln resumes its progress of desiccation.

The size of kiln here represented, would be sufficient for drying turf for all the tenants and inhabitants upon a large estate, or for preparing turf for a large distillery, steam mill, or other manufactory. Where the bogs are large, and in one connected locality, or range of country, the best arrangement would be for the landowner to construct one or more of these kilns at places suitable for the tenants, and charge a moderate interest for the capital expended, and for cost of maintenance to all those who had the right of Turbary—permitting turf to be made in no other way; and causing its use to be superintended by a steward or agent, until the first prejudice to the use of the novel method (which is unavoidably incurred) was got over, and the peasantry themselves became conscious of the advantages of the use of the kiln. At present the making of turf, is the most idle labour in which the Irish peasant engages; one which by its desultory nature, and

its entire dependance upon weather for a long continued period, has a strong tendency to induce lazy, half employed habits, but one which nevertheless consumes under the most favourable possible circumstances, about three weeks of the cottier tenant's year, and, during this time, the labour, or at least the time of all the able-bodied of his family: while under the disadvantage of broken weather, or a wet season, two or three months are often consumed in unavailingly endeavouring to make up the year's harvest of turf.

Yet, notwithstanding this serious deduction of time and labour, from those works of husbandry which should yield a good return, it must be fresh in the memory of all, from the experience of only two or three years ago, that when a summer of unusual wetness occurs, no expenditure of time or labour, will ensure to the Irish cottier, a supply of fuel for the winter; and that after much of his most valuable spring time has been unavailingly wasted in turning over and over sods of wet turf, which shall never dry, the winter comes upon him at his damp and cheerless hearth, without one vestige of fuel fit either for cookery or warmth, or light to dispel the gloomy images of weather unpropitious to the husbandman, gloomiest of all to him, the payment of whose rent depends upon the return expected from those crops which have failed from the same bad weather which has diverted his energies from their cultivation to the never ending labour of trying to make turf in time of wet.

If, therefore, the projects which I here bring before this Institution, are, as I believe them, competent at once to save at least three-fourths of the time and labour now consumed in making turf in Ireland—to get rid of the lazy sort of half labour by which it is at present made, and thus, act

with a moral advantage upon the peasant population; and to substitute for the chance of season and of weather, the absolute certainty of an annual crop of turf to the cottier, and of infinitely better quality than he has ever before obtained, and capable of being made up at any season of the year—that at which he has most leisure, in place of that at which the husbandman's time is of most value; if these be so, the carrying out of these ends is an object that ought to engage the earnest attention of the Landlords of Ireland, as well as those engaged in manufactures or trades, for which turf thus properly prepared, may be applied advantageously for fuel.

The cost of a kiln of the largest class, such as I have just described, would in most parts of Ireland not exceed £135. in many not nearly so much; to this must be added for 20 turf waggons, £80. This kiln would hold at once 10,000 cubic feet of turf, and from experiments I have made, and observations upon the results of drying other bodies upon the great scale, in kilns constructed upon these principles, I can state my conviction, that one such kiln would completely dry this quantity of turf, in six to seven days, with the consumption of 700 cubic feet, say, ten tons (dry weight) of turf mould, mixed with the tussocks, or dry fibrous masses from the top of the bog. The turf mould fuel need not be previously dried, (unless saturated with water) and its consumption would yield from four to seven per cent. of ashes valuable as a top dressing for grass lands and other purposes. The only labour required for attending the kiln, is one man to wheel fuel, and supply the fires, with the occasional assistance of another to introduce the fresh waggons of turf, and remove the dry at intervals of about 12 hours each. The turf should be all piled on the

waggons by children, but of this and the mode of cutting and preparing upon the bog, more hereafter.

When a whole estate could not be conveniently supplied from a single kiln, or when the demand might be smaller, or the kiln constructed by an individual for the use of one homestead, the following dimensions would be suitable:—

Length of chamber of kiln,	50 feet.
Height,	5 ft. 6 in.
Width,	4 ft. 6 in.
Fire place, (one)	5 ft. × 3 ft. × 2 ft.
Chimney stalk, (one) 3 ft. square in clear—height 18 ft.	

a kiln of this size would cost about £95. including the turf waggons, and would dry about 800 cubic feet of turf per week, with a proportionate consumption of refuse fuel.

For the cottier tenant, a still cheaper but still very effective kiln upon the same general principles may be constructed on the surface of the Bog, and principally of its materials. The two side walls of the kiln may be formed of substantial thickness, of well laid sods of turf from the surface of the bog, flat—bedded and turned upside down—these walls to be lined inside with a thin wall of dry stone, of which abundance is unfortunately to be found on the surface of almost every part of Ireland. The size of the chamber of the kiln might be 50 feet by 4 feet wide by 5 feet high; it may be covered with flags or slates if they can be had in the locality. If not, rough spars should be laid flat across from side to side, and covered over with common pan tiles, or neatly laid with flat thin stones, and over this a thick covering laid of the top sods of the bog in flat courses, cut neatly outside to a slope, so as to throw off the rain and form a roof. Where neither flat stones nor tiles can be had, the roof may be formed inside of wattle work laid upon, or rather secured

up to cross spars above them, and the wattled surface well plastered over with lime and hair mortar, so as to form a ceiling which will be sufficiently fire proof, and above this the roof of turf sods may be piled. From the bad conducting power of such sods, a kiln so made would act extremely well. The fire place may be made of dry stone at one side, sunk in the bog, and placed at a distance of 12 feet from the wall of the kiln, the communication to be from the fire to the kiln by a flue or drain of dry stone, which must be enlarged at one place to receive a sheet of wire gauze to arrest sparks. The chimney stalk may also be built at the remote end, of sods from the bog, strengthened by a layer of dry stone here and there, 15 feet will be a sufficient height, and 2 feet 6 inches square sufficient width. See Plate I. Figs. 1—5.

For waggons in such a kiln, coarse strongly made open *creels*, or baskets may be substituted, so formed as to pile above each other two deep, and fitted to the size of the kiln; these may be filled with the damp turf by children, and piled into the kiln, and removed by a man, or two women.

A single kiln of this sort, whose cost would be trifling indeed, might be a joint stock utensil common to four or five homesteads—but as all considerable changes, in modes of rural manipulation which have received the sanction of ages, must come either from the direct pinch of necessity, or from the influence of those classes whose education fits them to foresee advantages to which their less instructed dependants are blind, so it seems to me that the practical adoption of these improvements in turf-making must commence by exertion on the part of the Landowner, and not of the occupier alone.

The advantages afforded by this method of preparing

turf, are not confined however, to the saving of labour and the certainty of obtaining a crop of dry turf. The quality of the fuel obtained is greatly enhanced—it is absolutely dry, and in the process of *rapid* desiccation it shrinks to about half its former bulk, and becomes hard and woody, so that all the ends of the costly compressing process are by the latter consequence answered.

By results, obtained by myself, from trials made with steam engine boilers of various powers, worked by turf, I find that the consumption varies with the quality and dryness of the turf, and construction of the boiler and fireplace, &c. from 40 to nearly 80 lbs. of turf consumed to boil one cubic foot of water into steam at 212° Faht. from 60° Faht. Turf as usually prepared in this country in the most favourable weather, though feeling quite dry to the touch, contains still from one fourth to one third of its weight of water. Now it is obvious that in the burning of such turf, a large portion is consumed to waste in merely evaporating the water contained in its own pores. If we assume as an average that a given weight of turf in its usual condition as pronounced "dry" in Ireland, will convert into steam at 212° an equal weight of water, or 62½ lbs. of turf to the cubic foot of water into steam, then it is plain that for every four cubic feet of water usefully evaporated into steam, one cubic foot, or one fourth has been uselessly evaporated out of the turf itself, and that if this had been previously quite dry it would have nearly evaporated five cubic feet in place of four. It is quite true that fuel must in some form have been burnt in order to evaporate this fourth of its weight of water out of the turf, but it makes all the difference possible, in economic result, whether this be dried out first of all in an advantageously constructed

kiln by the consumption of a suitable quantity of otherwise refuse fuel, or evaporated in the furnace in the act of burning the turf. In the first case, the water is got rid of, at a minimum expenditure of fuel, and the desiccated turf is reduced in bulk and weight, and less labour therefore spent on its transport. It is more inflammable, and its combustion produces nothing but inflammable gases, in place of mixing these with steam often to such an extent that their combustion can scarcely be carried on: the extreme case being that of turf so damp that it will not burn at all.

But in the winter time this water remaining in the turf, is often frozen when the sods are thrown into the furnace or fire, in this case the loss is enormously greater than before, for its whole supply of latent heat has to be given to the ice before it can become water, and thus for every pound of ice concealed in the turf, as much of the latter is inevitably wasted in merely thawing it, as would be sufficient to heat an equal weight of water, 140° Faht. or nearly from freezing to boiling, after which an equal weight of turf is to be consumed in driving it off in the state of steam.

This may be made more clear by placing the results in figures before the eye. Assuming that turf of ordinary dryness, will evaporate into steam an equal weight of water, which is about the fact, and that such turf contains in its own pores, about 35 per cent. of water in the state of ice, then 62.5 lbs. of turf contain nearly 22 lbs. of ice, and as on these data .0559 lbs. of turf will heat a cubic foot = 62.5lbs. of water one degree, it will require 2.75 lbs. of turf to liquify 22 lbs. of ice.

There remain then 69.75 lbs. of turf containing 22 lbs.

of water at 32° Faht. To evaporate out this 22 lbs. of water, by our data, 22 lbs. of turf must be consumed, deducting which, there remain 47.75 lbs. of dry turf for useful effect, which will evaporate its own weight of water or rather more. So that in fact the useful effect of the fuel is in this condition reduced in the ratio of 47 to about 62, or there is a loss of nearly 25 per cent.: and this is very near the truth in practice.

The most exaggerated statements have been made by some authorities, upon which reliance is placed, as to the evaporative power of turf, and hence of its value as fuel. "One pound of pure dry turf will evaporate six pounds of water," Doctor Kane says (Indus. Resources, p. 35), on the authority of Peclet. However possible this may be, in experimenting with calorimetrical apparatus, certain it is, that the results of the most careful practice on the large scale fall immeasurably below it.

The City of Dublin Company's steamers on the Shannon are not "exclusively" worked with turf. It is found impossible to keep up steam, especially in bad weather, without an admixture of coal; but I have been enabled, by a discussion of their returns of both fuels consumed in given times and distances, to arrive at this result—that it requires 51 lbs. of turf, of the best quality and dry, to boil off one cubic foot of water into steam, on the average; and that under the boilers of those vessels about 8 lbs. of good South Wales steam coal are equivalent to 48 lbs. of turf; so that, for equal weights, the turf is worth one-sixth of the coal. These results were obtained by me in the course of an inquiry, having in view the working of steam-boat boilers, on the locomotive construction, with turf, upon canals in Ireland. Experiments were made with care, in

working with good dry turf; a locomotive boiler having the following dimensions:—

Fire-box, 3ft. 3½ wide by 3ft. 4 deep by 2ft. long.
Grate, 3ft. 3 by 2ft., = 6½ sqr. feet.
Tubes, 54 tubes—2½inc. diam. 6ft. 9½ long.
Surface exposed in fire-box,..... = 40.89 sqr. feet.
Surface exposed in tubes,..... = 240.04 sqr. feet.

Total heating surface,....280.93 sqr. feet.

When this boiler fully supplied its engines with steam, at 60 lbs. pressure above the atmosphere, it consumed 114 lbs. of gas coke, in evaporating the same volume of water as was done by 868 lbs. of dry turf. This gives the value of turf to coke in this boiler in the ratio of 1 : 7.61, which is below that given in the boilers, above alluded to on the Shannon.

The consumption was so rapid in the locomotive boiler that it was almost impossible to supply the fire, and maintain the draft.

The consumption of good dry turf, under a long cylindrical boiler, supplying a ten-horse high pressure engine, used in pumping water, and well set and arranged, erected under my own direction, was, on the average, 54 lbs. of turf for each cubic foot of water evaporated into steam, at 30 lbs. pressure, per square inch, above the atmosphere.

In a twenty-horse power condensing engine, erected under my direction (by our firm), with waggon boilers, which were already in existence, the consumption of tolerably good dry turf averaged from 57 lbs. to 60 lbs. for each cubic foot of water, evaporated into steam, of about 5 lbs. pressure above the atmosphere.

In a thirty-five-horse power condensing engine (Sheane and Beales, Mountmellick), the largest I have found

worked with turf in Ireland, I found, last year, the consumption varied from 55 to as high as 80 lbs. of turf to the cubic foot of water, evaporated into steam, at about 7 lbs. above the atmospheric pressure. The boilers are well set, and the furnaces well calculated for burning turf, which, however, was not quite dry (even to the hand), and only moderately good in quality. Coal at 16s. per ton would have been quite as cheap; and if the turf were a little more damp, as in the winter time it would be, coal would be the cheaper fuel. If the turf had been quite dry, on the contrary, I calculated that the saving by its use, in place of coal at 16s. per ton, would amount to about 6s. per day, of twelve hours.

Blavier, Tredgold, Clement, and Desormes, all trustworthy and unbiassed authorities, give 53.6 lbs. of turf as the average amount to convert a cubic foot of water into steam; and as their results are quite confirmed by my own observations, I conceive it may be taken as a safe datum for practice, that a given weight of turf of the best quality, as usually now prepared in Ireland, will not, on the average, convert into steam more than its own weight of water. I believe, by proper preparation of the turf in cutting, and by complete drying in a kiln, that this result might be nearly doubled; but even so, the result would be only about one-third of the values assigned by Doctor Kane and Mr. C. W. Williams, whose statements, on this subject, are calculated to lead to much disappointment and loss.

It has been before stated that kiln-dried turf is very hygrometric, and has a strong tendency rapidly to re-absorb part of the moisture which it thus loses. For manufacturing purposes, turf thus prepared should be rapidly used; but as this is not always possible, and as

the value of the method in its more universal application to preparing turf for domestic use, where it must lie for a considerable time before being burnt, would be limited merely to giving the power of obtaining a crop of turf, independently of season or weather, if it were the fact, that kiln-dried turf afterwards re-absorbed all the moisture it lost, and returned to the state of air-dried turf, I therefore made a careful series of experiments upon turf from the Bog of Allen, having for objects—

1.—To determine the water contained in dense black and light red turf, both air-dried.

2.—The loss of weight and bulk, &c., in drying in the kiln.

3.—The amount of hygrometric moisture regained by exposure to the usual atmospheric influence, but free from rain or dew.

4.—The amount of ashes contained in each sort of turf tried.

The black turf experimented on was of the most superior quality, taken from a depth of twelve feet in the bog, being three feet or more above the bottom of the bog. One cubic foot of it, air-dried, weighs 43 lbs = 1161 lbs. per cubic yard. The statute box, of 20 cubic feet, of this turf, weighs = 671 lbs—piled in sods, = 33.5 lbs. per cubic foot = 904.5 per cubic yard.

The red turf was taken from within three feet of the surface of the bog. It was fine fibrous, free from roots, &c., and of good quality. One cubic foot of it, air-dried, weighs 17.25 lbs = 465.75 lbs. per cubic yard. The statute box of 20 cubic feet weighs 276 lbs.—piled in sods, = 13.8 lbs. per cubic foot = 372.6 lbs. per cubic yard. Both sorts felt quite dry to the hand.

A quantity of each sort was dried for four days in a

stove or kiln, at a temperature of 180° Fahn. or thereabouts. It was accurately weighed before and after drying. The results were as follow:—

The cubic foot of black turf, which before weighed 33.5 lbs., when now thoroughly dry only weighed 28 lbs = 756 lbs. per cubic yard. The loss of moisture was, therefore, 15 lbs. per cubic foot = 405 lbs. per cubic yard = 34.8 per cent.

The cubic foot of red turf, which before weighed 17.25 lbs., when now thoroughly dry only weighed 14 lbs. = 378 lbs. per cubic yard. The loss of moisture was, therefore, 3.25 lbs. per cubic foot = 87.75 lbs. per cubic yard = 19 per cent. nearly.

The black turf, therefore, when air-dried, retains nearly twice the moisture, in proportion to its weight, that the red turf does—the former holding about one-third, and the latter about one-fifth of their respective weights of moisture.

Both sorts of turf were now left exposed to the air, under cover of a roof, for several weeks, in the months of October and November. The specimens were then again weighed to determine how much moisture they had re-absorbed.

The cubic foot of black turf now weighed 31.07 lbs. = 838 lbs. per cubic yard. The weight of moisture regained was, therefore, 3.07 lbs. per cubic foot = 82.89 lbs. per cubic yard = 7.14 per cent.

The cubic foot of red turf now weighed 14.84 lbs = 400.68 lbs. per cubic yard. The weight of moisture regained was, therefore, 0.84 lbs. per cubic foot = 22.68 lbs. per cubic yard = 4.87 per cent.

Thus it appears, that under the most severe trial, namely, exposure to the air of nearly the dampest month

of the year, and for a period of at least five weeks, the black turf only re-absorbed about one-fifth of the moisture it lost in kiln-drying, and the red turf re-absorbed about one-fourth what it had lost. Hence, the latter is the more hygrometric of the two; it more easily parts with, and re-assumes its contained moisture.

By kiln-drying the black turf shrinks about one-third of its volume. The red turf, as much as one-half in many specimens, but in some, not one-fifth of its original volume—the difference depending upon the nature of the fibrous vegetable matter composing it.

The black turf produces, when burnt, 5.74 per cent. of light fawn-coloured ashes = 128.5 lbs. per ton = 1.6 lbs. per cubic foot = 43.2 lbs. per cubic yard. These ashes contain of sulphur, in the state of sulphates, 0.253 per cent. of the weight of the turf itself. They also contain a trace of siliceous *sand*, washed down into the bog.

The red turf produces when burnt 1.13 per cent. of perfectly white ashes = 25.31 lbs. per ton = 0.16 lbs. per cubic foot = 4.27 lbs. per cubic yard. These ashes contain sulphur, as sulphates = 0.107 per cent. of the weight of the turf.

Thus it is proved that the red turf contains only about one-fifth as much ashes as the black turf; but it contains nearly one-half as much sulphur in its ashes as the black turf does, in equal weights of both. From these experiments it may be concluded—

First, that the artificial drying of turf, by kiln, is attended not only with the important advantage of insuring a crop of perfectly dry fuel, independently of season or weather; but that an increased value is given *permanently* to the turf in the process.

Second, that this method of drying increases the value of turf fuel of the best quality, as ordinarily prepared, by nearly double.

Third, that the method is applicable not only to turf, intended for immediate manufacturing or other use, but to all turf requiring to be stacked or stored for future or domestic use.

Fourth, that the most valuable return is given by applying this method of drying to the dense black varieties of turf; and that the assumed advantages of superior purity in the red, or upper turf, for certain manufacturing uses, are not founded in fact; inasmuch as its ashes contain a considerable proportion of sulphur, as well as those of the denser black turf.

Enough has been previously said as to the greater economy of time and labour in the preparation of turf by this method, than by air-drying by hand. I shall, therefore, pass to the last subject of this paper, viz., the method of cutting turf, or rather of detaching it from its site in the bog, which I would propose to be universally substituted for the present method of cutting with the *sleane*, as practised in Ireland.

In this I propose merely to introduce to practice in this country the methods which the ingenuity and long experience of the Dutch have shown them to be attended with the happiest results. The method may be expressed in a single sentence; it is in place of ever *cutting* turf from the bank in sods at all, invariably to make "hand turf," as it is called in Ireland. Wherever there is abundant water in the bog, as is generally the case, the peat mud for this purpose is to be had ready to hand, merely by taking it out of the bog-holes by suitable instruments. Where the drainage is more perfect, or the turf more

fibrous, the Dutch method of working, or kneading with water, so as to make artificial hand-turf, must be adopted. The results of adopting this method are—that from the same peat, turf thus made is about double the density when dry that it can ever be brought to without mechanical pressure, if cut in sods—that the whole labour of turf-making is reduced to merely casting out the peat mud, and spreading it on the surface of the bog, when properly prepared to receive it, and after a short time slicing the semi-dried stratum of peat mud with a fit tool into parallel bands, to form the future peats, which, as soon as they are consistent enough to be carried, are transferred to the drying kiln, by which the whole labour of spreading and turning the sods and piling, &c., which constitute by far the greatest expenditure of labour in turf making when cut in sods, are avoided.

The making of hand-turf in Ireland is comparatively very little practised; although well made hand-turf is confessed on all hands to be the best fuel that the bogs afford. Why is this? Simply because no one in this country has hitherto seen the reason of the better quality of hand-turf, or observed the great economy of labour in its preparation. In fact, it is generally, I observe, regarded in Ireland as the last resource for fuel of the most destitute, of those who cannot command labour enough to *cut* turf; yet the fact is, it is the method that ought to supersede cutting altogether.

In the northern provinces of Holland the bogs are almost marshes, the water generally stands within a few inches of the surface, and the method of obtaining turf is as follows: A long channel of from ten to fifteen feet in width is opened along the bog, by removing the peat to a sufficient depth to enable a flat-bottomed boat to float and

traverse the shallow canal. The stuff excavated from the canal is first made into turf, by the method about to be described, and afterwards the canal is widened and deepened by dredging up peat mud, and depositing it along the banks. Transverse canals are also used; and thus the cost of transfer of the peat mud is reduced to a minimum. As the excavation deepens, where it is possible the water level of the canals is lowered somewhat; but the peat to be extracted for fuel is kept always covered with water.

The peat mud when dredged or dug out, is thrown into a flat wooden tray or trough, usually about 8 feet long by 4 wide, of fir plank, 1½ in. thick, with edges of the same, rising about 8 inches, and sloping outwards to an angle of about 35 degrees with the vertical; it is here trodden by boys or women either in "sabots" or more generally with naked feet, and all unbroken masses of the peat are thus with great rapidity broken up, and the whole reduced to an uniform fluid pulp or thin mud; this is thrown into box barrows and transferred away, and thrown upon the drying floors, on the surface of the bog, where it is spread to an uniform depth of about 8 inches.

The operation of division is occasionally assisted with the more fibrous sorts of turf, by the use of a short four-pronged flat fork, like a dung fork, and in some places, the prepared mud is not barrowed to the drying bed, but thrown at once into the kneading trough, which has got a moveable board or edge at one end; when this is taken away, the peat mud is scraped out with a tool like a scavenger's hoe or scraper, on to the drying bed and the wooden trough is then moved on altogether to the next space to be covered.

The preparation of the drying floor consists simply in levelling, or reducing to a very slight slope, a sufficient portion of the bog surface, over which, when the locality

affords it, about six inches in depth of sand or fine gravel is spread, and when more than usual care is taken, some French drains are previously made beneath it to the depth of about a foot or so. The sandy surface is smoothed with the shovel like the floor of a brick yard; and upon this the peat mud is spread out.

Where sand is not to be had, or any substitute for it, the peat mud is spread directly upon the surface of the levelled bog with French drains at intervals, previously made in it. After a few days have elapsed, more or less according to the weather &c., the bed of mud has lost enough of water by filtration and evaporation, to be divided in one direction: a long straight edge of light wood, is laid upon the surface, and a man or woman with bare feet, goes along upon it, and with a particular sort of tool divides the mass into long parallel ridges or strips at intervals of from 6 to 8 inches. The direction of these ridges is not indifferent; they have reference to the direction of the Sun and are so managed that for the greater part of the day the sun shall shine right along the furrows, and so not cast the shadow of one ridge upon the next, and therefore impede the drying.

The tool with which this division is performed, is a sort of spade with a short handle and flat blade, cut off bevel at the point, thus:

These dimensions are only from memory, but are pretty nearly correct; sometimes the iron handle at top is made

long enough to take both hands, as an auger is held; the tool sketched however seems to be the favourite.

In a few days more, the bed of parallel bands of peat mud, like our hand turf, has got so consistent that they will bear to be cut transversely in the same way; this is not done quite at right angles, but the lines of ridges cross at an angle of about 65° or 70°; the peat sods are said to separate best in this way. In a day or two more, every second ridge is lifted up, and the peat sods are turned upside down and across the space between the ridges. They are then removed and piled in twos and threes, and the others are turned up, and so the subsequent drying proceeds as with us.

The dredging tools used for lifting the peat mud vary: in some places, very awkward *looking* mechanical dredges of timber are used which bring up a cubic yard or more at once, but generally hand dredges consisting of a leather bag, upon an iron hoop with a cutting edge, and mounted to a fit pole, are used from the side of the boat, or sometimes from the bank, the footing of the men being secured by their standing on an open moveable grating of fir timber.

The rim or hoop of the hand dredge is an ellipse of about 18 inches by 13 in. The leather bag is perforated towards its upper part to free the mud from some water—the sizes of the dredges vary also with the strength &c. of the persons using them.

I have not seen kiln drying in use in Holland: that improvement still remains to be adopted by the Dutch, and hence the labour of turning and piling the turf, although immeasurably less with this "moulded" turf as we may call it, than with cut turf, is still considerable. But all the prior operation or rather the principle of breaking up

the fibre of the turf as it exists in the bank, and moulding it as mud, into turf, in place of cutting it with the "sleane" is what I would urge for our adoption from the Dutch, and to superadd to their arrangements the completion of the drying of the turf in kilns as soon as it is hard enough to be transferred to them from the drying floor.

The value of breaking up the fibre of the turf as it exists in the bank, has been seen by several persons, in these kingdoms, though unfortunately the methods they have proposed for doing so, are far too expensive (like the methods of compression) ever to be brought successfully into use. Thus the patent of Michael Jenning of Edinburgh, dated 6th February, 1837, for preparing peat fuel, prescribes to grind it by edge stones, or in a pug mill, to mould it then like brick-making, to dry it in a stove, and lastly, to char or coke it.

Mr. C. W. Williams, in his patents of a subsequent date, in November, 1837, and July, 1838, directs the peat to be ground with limestone, coal, or hot lime, to be compressed in wrappers of coarse cloth, and subsequently to be dried before and after pressure by a fan blast, and charred or coked in a stove. And I understand that at this time a patent is in progress, or has been sealed for other and much more simple and inexpensive methods of breaking up the turf fibre, by a gentleman of the name of Cobbold. In Ireland, from the nature of the bogs, and the suitability of their natural supply of water, abundance of peat mud can be commanded ready made by nature, and only requiring to be spread out and dried, but wherever further separation or mixing are requisite, they can be done rapidly and cheaply by the Dutch method, and never need such ponderous machinery and ungainly con-

trivances as edge stones or pug mills, for separating fibres that the motion of an infant's hand will suffice for.

It is not perhaps easy to give any precise explanation of why it is that peat dries so much faster, and becomes so very much closer and denser, if broken up prior to its drying, than if dried just as cut from the turf bank; but the fact is certain. Thus I find by actual experiment, that good brown turf from the bog of Allen, when kiln dried as cut from the bank, weighs only 31 pounds per cubic foot = 837 lbs. per cubic yard. When cut, and the fibre broken up moist, and made in the Dutch fashion, and kiln dried, it assumes, such a density as to weigh 64.6 lbs. per cubic foot, = 1744.2 lbs. per cubic yard; thus more than doubling its density, and in fact becoming as dense as compressed turf, and denser than dry oak timber, which only weighs about 53 lbs. per cubic foot.

The average cost in Ireland of turf may be stated at from 5d. to 7d. per statute box of 20 cubic feet. Now it is said, that one able-bodied man can cast up from a bank, not more than 5 feet in depth, as much as 20 boxes = 400 cubic feet per day of wet turf sods. I doubt the fact myself, but assuming it to be so, it will require from four to five other persons (women and boys) to carry away and spread the turf, and under the most favourable weather, the turning and piling process must be continued for at least 20 days. Taking the average of wages in Ireland, therefore, it is manifest that almost the entire value of turf at 6d. a box consists in labour spent upon it. Now if the Dutch method, or the Dutch improvements on our own method of making hand turf be adopted, at least two-thirds of the whole labour would be saved; and more than this, if, as I recommend, this method of preparation be fully combined with the arrangements for

desiccation in kilns which I have proposed. Thus then, to recapitulate: what I propose for improving the preparation of turf fuel in Ireland is—

First, to abandon turf cutting altogether, and exclusively make "hand turf" after the Dutch method.

Second, to dry all turf so made in kilns, either of the German, or of my construction.

The advantages which I propose are—saving of labour and time—devoting the most leisurely in place of the most busy part of the agricultural year to turf making—obtaining a crop with certainty, independently of season or weather—improving the quality of turf at least twofold, no matter what its natural description may be.

Should these suggestions happily meet the attention, which I believe their adoption deserves—not only will these results be obtained, but turf will be applied to very many purposes of manufacturing industry in Ireland, to which, otherwise, it has not the remotest chance of being suited; and in time, the preparation and sale of turf fuel may become in Ireland a great and important trade, fostering and sustaining many others like the coal trade of England.

The preservation of turf and the modes of stacking it, need great improvement; it seldom is kept under a roof, unless by the wealthy in Ireland. But I find this paper has already extended to too great a length, to permit me to enter on this part of the subject, further than to remark, that it would form a valuable subject for a prize Essay for some of our agricultural societies, to devise the best and cheapest sort of roof for covering the turf stacks of the peasantry and cottiers, and the best methods, generally, of stacking turf in this country, so as to *free it from surface damp*.

All that I claim to be considered as novel in this communication is the construction of kiln I propose, and some experimental proofs of its value.

The original idea of drying turf in kilns is due to the late Thomas Tredgold, a man whose ingenious and fervid mind has left in his works a mine of thought and invention, from which many have borrowed without acknowledgment. I would not be of the number. For the rest, I have only endeavoured to put in a clear light, the results of observation, as to the useful arrangements of other countries, or to show the importance of one of the nearly neglected methods of our own.

[November 26th, 1844.]

The following communications were read:—

"*On the* CONSTRUCTION AND USE OF THE DIVING BELL;" by WM. FORSYTH, C.E. Associate.

THE best contrivance of this kind is the bell generally attributed to Smeaton, and improved by Rennie. Various modifications have been introduced by others, and different sizes have been tried, some larger and some smaller than Rennie's, but, for the general purposes of Hydraulic Architecture, this bell has maintained its superiority, and is in general use while the others are abandoned. It is, however, not without its defects; and these defects are severely felt by those engaged in particular branches of these operations. The most prominent are the following: Its great weight, and the being compelled to use one uniform weight for all depths and purposes, coming within the range of its operations.

In constructing the submarine foundations of Piers, &c. at a great depth, this weight is absolutely necessary; it has even been found that the mechanical contrivances used for managing the bell, have but little command over it, from its buoyancy at such depths. The great weight being in the substance of the bell itself, gives it greater compactness than if the weights were foreign to its own substance, and merely attached to give it preponderance.

It has also been found, that building under water to seaward, even at small depths, weight, strength, and compactness are highly necessary, as the agitation of the sea drives the bell about with dangerous force, notwithstanding its weight; and the shocks it has to sustain, when driven against stones, might displace attached weights, and destroy a weaker machine.

These are facts which have been proved by experience, and they are of importance to those concerned in hydraulic operations of this kind. But in sheltered harbours, lakes, and rivers, where the depth is often small, and the water still, the bell is not exposed to a force that would displace it, derange any of its attachments, or endanger its structure. And there are many operations, such as blasting rocks, making excavations, lifting stones, &c. where it would be of great advantage to possess a light machine, which could be easily transported from place to place, and even taken asunder to facilitate its transport, and which would require little time or skill to rig it up; and besides dispensing with much of the gigantic machinery by which Diving Bells are now worked, to be able to regulate the preponderating weight according to the depth at which the operations are being carried on. This is not so difficult of attainment as might be supposed, from viewing the bell now used for building, with its expensive but complete outfit.

Other defects may also be mentioned, such as the size or horizontal dimensions when the bell is used in confined and uneven localities, defects in workmanship arising from the manner of its construction, and its liability to be cracked or broken, so as to make it difficult or impossible to repair it in such a manner as that its efficiency should not be lessened; but these defects arise from the localities where the bell is used, or casualties in the material and workmanship.

Bells constructed of timber have been used, even for building purposes, with considerable success; and for lifting guns, anchors, merchandize, &c. from wrecks, or places where they have been lost overboard, a bell constructed of timber, and jointed with canvass, so as to fold up, has been used. There is nothing to prevent such machines being used, as the pressure which they have to resist, is seldom more than three or four pounds per square inch; but they are so fragile that their use could only be temporary at best.

The extensive application of sheet iron, especially to hydraulic purposes, at once points it out as the most durable and economical material that can be employed, and as possessing all the properties necessary for constructing a light portable bell, capable of being loaded to an extent to suit any depth of water.

It appears that the first instance recorded, in which sheet iron was used in constructing a diving apparatus was the result of necessity; and it is described in the 54th Vol. of the Transactions of the Society of Arts, Manufactures, and Commerce, page 97.

The size of the Diving Bell for general purposes ought to be the same as Rennie's bell—no improvement, I think, can be made in this respect. The size of Rennie's bell

is 6 feet 4 inches long, 3 feet 10 inches wide, and 5 feet 4 inches high, internal dimensions. To add to its dimensions in any way would be to add to the weight necessary to sink it; and although this weight would be neutralized by the included atmospheric air when immersed, yet the whole weight would have to be borne when the bell was lifted out of the water; or else the weights removed when it came over water; either of these would be attended with cost and inconvenience. Jumpers of any length can be used in Rennie's bell. It is only necessary to have them in suites, increasing in length in a certain ratio, so that they can follow each other. If the hole to be bored be a vertical one, when it is put down so far as to make it necessary to introduce a longer jumper than can be turned within the bell when set on the bottom, then all that has to be done is to have the bell hove up to a sufficient height to allow the jumper to be introduced, and lowered down again, and this is the work of a minute or two only. If the hole be horizontal or inclined—what is technically called a lifting shot—then instead of the bell being raised it has to be moved to one side, the long jumper introduced, and the bell then returned to the former position. There are many of these little contrivances known to the workmen practised in this kind of work, which enable them to surmount many seeming difficulties.

For blasting rock in depths under ten feet, much time and expense would be saved by the following plan. Let the workmen in the Diving Bell select a proper place for the proposed shot, and enter a hole, say twelve inches, then jumpers of sufficient length could be introduced to enable the hole to be completed to any required depth from a flat—similar to the boring flats used on the Shannon—or from a raft or scaffold. When the hole is completed to

the required depth, the charge can be put in and stemmed by the workman in the Diving Bell; and as it is seldom that less than three yards of fuse are used for the safety of the workmen, the end can be brought to the top of the water and fired.

If this plan be followed, about one half of the usual cost of boring under water would be saved, as the Divers would have little more than a fourth of the work to do. The numerous attendants on the bell, and the necessary slowness, in comparison to working on a lighter or raft, will warrant these statements. If the rock be of such a kind that horizontal or inclined holes are necessary, this plan cannot be followed, but a hole inclined fifty or sixty degrees may be bored in this way.

The more extensive the work, the greater the advantages to be derived from this plan. The diving apparatus being completed, the bell-men enter three or four holes, at such distances from each other that one will not neutralise the effects of another. Let the men on the raft follow, drilling the holes to the required depth; and when they have a few completed, the bell-men will return, charge the holes, and after they have been fired, lift the detached rock, and enter other holes. By this process, the men on the raft will be kept employed without intermission, and the whole progress simultaneously until the completion of the work. The more that can be usefully added to the establishment the less the cost of the whole work, as the portion done by the Diving Bell will be less. The number of attendants on the bell, whose work does not immediately tell on the excavation, is what adds so enormously to the cost of this kind of work.

To make the internal economy of the Diving Bell

intelligible, a section of Rennie's bell is given, Pl. 3, Fig 1.

A, is the footboard which is moveable, and seldom used, except when descending and ascending. BB, two seat-boards, these are also moveable, being inserted between raised flaunch brackets, cast on the side of the bell. C, a timber rail, wedged between the two ends of the bell, and placed in the angle which the top and sides make—there is one on each side. Malleable iron hooks are driven into these rails, from which the tools are suspended, viz :—two setting bars, a shovel, one or two boring hammers, a three feet rod, several chains, and the signal hammer. These are the tools always necessary, excepting the shovel. For occasional work, such as boring, there are jumpers and tampers of various sizes ; but these, and heavy chains and hammers, are left lying at the bottom when not being used or undergoing repair, D, are the inside coupled chains ; these are also made so as to be detached with ease. E, the air valve attached to a brass grating of the form shewn, Fig. 2, which is secured to the top of the bell by screw taps. The valve is simply a disk of strong leather, held in its place by the screw taps which fix the brass grating to the top of the bell. F, the coupling chain, by which stones and other weights are lifted. G, the line at which the water usually stands on the inside of the bell, when the air hose is in good order. H, the lewis. I, stone suspended by the lewis and chains. The use of the greater part of these is obvious. The use of the internal coupled chains will also be understood by the manner in which the stone is represented, as suspended, in the sketch.

If we supposed, for illustration, a stone to be lowered down ; the bell is then brought over it, and made to rest

slightly on the stone to steady it. The chains by which the stone was lowered down are then detached; the lewis having been inserted into the stone before it was lowered, is attached to the inside coupled chains in the following manner: the chain F, which forms an indispensable item in the furniture of the bell, has a hook at each end, one much stronger than the other; the strong hook lays hold of the ring which couples the two inside chains, D. The other end of the coupling chain is run through the ring of the lewis, and either hooked into the ring beside the large hook, or, what is more common, four large links are made on the end of the coupling chain, F, next the large hook, and into one of these the small hook is hooked, suiting the length to the proper distance between the bottom of the bell and the stone when suspended. When this is done, the bell is then hove up, and as the stone is attached to the bell by the chains, F and D, the stone is also hove up, and, when high enough, carried away, in obedience to the signals.

When the bell is prepared for boring, every implement that can be dispensed with is removed to make room. One or both of the seat-boards are taken out to make seats on the rock, or scaffolds to stand on. If the hole be a horizontal or inclined one, it is necessary that the bell be so far raised as to allow the jumper to be put out under the end of the bell; then the foot-board and seat-boards are made into a scaffold by suspending them from the hooks in the timber rail, by lanyards or gaskets. When the hole is bored, the bag or cartridge is introduced, and tamped in the ordinary way, only clay will not answer, it becomes too soft with the water—soft burnt brick must be used. About three yards of fuse being left attached to the bag, the seat-boards and foot-

boards are replaced, the end of the fuse is kept in the bell, which is now removed as far as the length of the fuse will permit. The fire is then applied, and the bell removed farther—about five or six yards in all—from the shot, This is quite far enough for safety, as no fragments will be able to force their way through the water to do any injury.

I have designed a sheet iron Diving Bell, represented Plate III. Figs. 3, 4, 5. I have made it the same as Rennie's bell in size, although I think a smaller bell might be occasionally used with great advantage; but this size, as I have already stated, I think the best, when two or three workmen are to be employed. The plates I propose to be $\frac{3}{8}$ or $\frac{7}{16}$ of an inch thick, 6 feet 6 inches long, by about 2 feet 3 inches broad, or any other dimensions that may suit better. These plates to be placed in the manner shewn on the drawings—that is, the seams or joints of the sides and ends to be vertical, and the lower ends of the plates turned up so as to form a receptacle for the ballast weight. As the length turned up will not give sufficient depth to this receptacle—or what may be called pocket—I propose that a plate be joined horizontally, or its length parallel to the bottom of the bell, and continued quite round, forming a continuous band to give strength to the pockets at the corners, where the plates are necessarily cut to allow them to be turned up at the bottom. I propose the pockets to be 20 inches, or more, deep. If 5 feet 4 inches—the height of the bell be taken from $6\frac{1}{2}$ feet—and 7 inches for the semi-cylindrical bottom of the pocket from the difference, there will remain only 7 inches of the side and end plates to be turned upwards for the outside of the pockets. It will therefore require a plate 16 inches, or more, broad,

allowing for the seam, to make the pocket of the proposed depth, not taking the semi-cylindrical bottom into account. Instead of piecing each turned up plate with 16 inches in length, I take four plates, about 6 feet long each, and 16 inches broad, which, when joined together by rivetted seams, will make a continuous band entirely round ; and this band is joined to the turned up ends of the vertical plates by a rivetted seam.

To this continuous horizontal plate are attached knee-plate stays, 4 inches broad, and half inch thick. These stays are rivetted to the sides and ends of the bell, three on each side, and two on each end. The top of the bell is attached to the sides and ends by angle iron, such as is used in the construction of steam boilers. The corners of the bell form a portion of a cylinder—6 inches radius —to facilitate the bending of the plates, and avoid straining them ; this will also assist the bending of the angle iron round the corners and ends of the bell. The cylindrical corners of the bell make it necessary that about 12 inches in breadth be cut out of the middle of the plate, from the line which terminates the vertical part of the plate forming the body of the bell to the end of the plate. When the portions of the plate remaining after this piece is cut out, are bent upwards, the ope must be covered with a piece of plate forged to the proper figure. The cutting and forging of the corners of the pockets will leave them weaker, and therefore it is desirable to have the continuous band to strengthen them.

The top of the bell is formed of two pieces of plate of unequal breadth, to avoid having the rivetted seam in any of the perforations. A bar of iron is placed on the top, and extending its whole length, except where the air hose is attached to the top of the bell, and turning down

on each end. The general dimensions of this bar are two inches square, and thinned towards the inverted ends; and having two pedestal formed parts, as shewn, to receive the shackle bolts of the coupled chains by which the bell is suspended. These shackles, bolts, chains, and ring to be the same as those of the bell now in ordinary use. A similar bar is on the inside of the bell-top, but shorter, not having its ends inverted. These bars are to be attached to each other, and to the bell-top, by four rivets, of 1¼ inch round iron, rivetted hot; and the two inverted ends of the top bar to be secured to the ends of the bell by one rivet each. To the inside bars the coupled chains for lifting weights are attached, by shackles and bolts. The screw-joint for receiving the end of the air hose, and the valve on the inside of the bell, to be of the same materials and construction as the bell already referred to. The perforations for the lights to be 5 inches in diameter, the lenses 7 inches in diameter, and 2 inches thick in the middle. The lenses to be secured with glands, hemp, and luting of red or white lead, and fastened to the top of the bell with screw-taps. The number of lights to be eight—the usual number is ten. The position of the two deficient ones is occupied by the bar above described. This bar I thought necessary to prevent straining the angle iron, by which the top of the bell is attached to its sides and ends; and perhaps it may be advisable to have two other bars placed at right angles to this one, proceeding from the pedestal parts, and turning down the sides of the bell, and rivetted in the manner before described. These bars are not shewn on the drawings, but if they be thought necessary they can be added. The seat-boards and foot-

boards to be supported by angle iron, rivetted to the sides of the bell.

The air pump and air hose, or pipe, to be the same as those in general use.

The ballast to be of cast iron, moulded of such shapes as will fit the pockets, and provided with handles sunk below the surface.

On an emergency, or where it might not be convenient or advisable to transport the ballast, malleable iron bars of suitable lengths, and any scantling, may be used, so that they stow into the pockets and fill them.

If the weight of the bell (about 32 cwt.) be found too great for transport, it may be made in two divisions—see line, *c d*, on the drawings—and joined together by a series of screw bolts, instead of rivets, and having a band of hemp or canvass luted with red lead interposed between the parts to make the joint air tight. It is, however, evident that this ought to be avoided if possible.

I hinted above that a bell of smaller dimensions might be used in many instances with great advantage. This bell I would construct of the same materials, form, &c. only I would make its length and height, respectively, 4½ feet, and the breadth 3½ feet. This would be quite large enough for one man; and in many operations, such as chaining stones, or lifting wreck, a single individual would be sufficient, and could work with much more freedom, comfort and safety, than with the helmet. For light single handed boring, two workmen might descend and relieve each other by spells, as it is not possible that the workmen can continue to exert themselves in the bell without respite, on account of the increased pressure they have to sustain. This increased pressure soon exhausts them when working hard, and the excessive breathing

proves prejudicial to their health. Two men in such a position, spelling each other, are only equal to one on the top. There would be quite room enough for one to sit while the other is at work.

If such a bell as this were used, the displacement would be so small that much less weight would be necessary; consequently, a lighter outfit would be sufficient for managing the bell. This would extend the benefit of this useful machine to many cases at present quite impracticable.

The weight of the large bell with chains, bolts, bars, ballast, &c. &c. would be about 4¼ tons. The weight of the small bell about 3 tons.

It may be stated, that one of the advantages of this kind of Diving Bell is, that the ballast weight can be varied to suit the depths at which the operations are being carried on; thus preventing the necessity for using any more than is just sufficient.

While on this subject, I would notice another matter connected with these machines, although not belonging, strictly speaking, to the Diving Bell itself—that is, the affording a plentiful supply of fresh air to the forcing pump. If the pumps were placed in the open air, as formerly, this is at once secured; but it has been found advantageous to shelter the workmen at the pumps by small boarded houses or sheds. This is advantageous, not only for sheltering the men from the inclemency of the weather, but for preventing their attention being diverted, so as to neglect the important work they are engaged in. This shed, or house, is generally placed on the end of the frame from which the bell is suspended. The frame being necessarily moveable, the wind, when high, exerts such force on the house as makes the working

of the frame slow and laborious. To prevent this as much as possible, the shed, or house, has been contracted to its least possible dimensions. In this small box, for it is nothing else, are four men, sometimes six, stripped, and generally, unless the weather be very cold, perspiring profusely. The box is filled with the exhalations from their bodies, nearly excluding every atom of fresh air. It is this deleterious compound, for atmospheric air it cannot be called, that is pumped down to the workmen in the bell, who are already, perhaps, labouring under the pressure of an additional atmosphere more than nature designed them for. And we may add to this, that in many cases the expirations from the diseased lungs of the workmen at the pumps are mingled with the foul fluid supplied to the bell, instead of the pure atmosphere so necessary to vitality, and doubly so to those in such a position.

The remedy is simple: nothing more is necessary than to attach to each barrel of the forcing pump the end of a tube, or inverted cone, of strong canvass; the other end passing through the top of the box, surmounting it to a small height and kept open, in the same manner as the holds of vessels are ventilated. These conical tubes may be made of thin deal boards. By this simple process, an abundant supply of fresh air will be always procured, and the pump defended from the impurities floating in the pump-house.

"DESCRIPTION OF A NEW INSTRUMENT *for passing a chain or hauser beneath and round bodies, sunk in deep water, or in a rapid streamway, without the aid of diving apparatus, called by the inventor,* 'THE WATER NEEDLE;' by R. MALLET, MEM. INS. C.E. M.R.I.A. &c. &c.

IN the year 1843, in the depth of winter, some large castings, weighing from ten to twelve tons each, were sunk in a rapid of the river Shannon, at Lodge Cut, near Cloondra, Co. Longford, by the bilging and sinking of a lighter, in which they were being transported to Athlone, to form part of the new Swivel Bridge, there.

The castings were thrown off the deck and sunk in water, which, before any effectual means could be taken to recover them, (owing to technical difficulties as to freight and damage) was raised by the winter floods to the depth of from eight to nine feet, and ran with the velocity of about six miles an hour.

Some attempts were made to examine or attach chains to the castings, by naked diving; but the power of the current was such, that a man was powerless when immersed—the diving helmet could not be worked for the same reason, and no diving bell was to be had nearer than Kilrush. Circumstances, connected with the execution of the work at Athlone, obliged the immediate recovery of the castings, (without waiting for the waters to fall to summer level,) or to substitute new ones for them. Under those difficulties the following instrument was designed and put into use by Mr. Mallet, for the purpose of passing one or more chains under the castings, which when done, they could be easily lifted. The success which attended its use was so complete, that the inventor has thought it worth recording, for the purpose

of helping others in similar cases of difficulty. By examination from a boat with a pole, aided by the "water telescope," a tube of copper, glazed at bottom with a plain strong glass, and weighted to sink in the water, and guyed by two cords so as to resist the current, an instrument well known for a long time, though but little used, it was found that the castings rested upon an uneven bed of gravel and shingle with large boulders, which, by having been sweept along with the stream, had partly buried them; but that in some places a bent rod could be thrust beneath some of the ribs of which these large castings of framing consisted.

The instrument contrived was as follows:—a long slender fir pole, A, fit for a boat hook handle, and suited to the depth of the waters, socketed at its lower end to the L shaped socket and round bar, B, of ⅛ in. round iron; this carries in slots at C and D, two small brass sheaves, of two inches outside diameter, and fitted for carrying strong "fishing line" cord. E, is a ball, or hollow sphere of thin copper, quite air tight, with a small eye at one side, to which the fishing line cord is fastened at one end, the other end of the line is passed under both sheaves, C and D, and carried up to the top of the pole, at F, where it is wound round and made fast, after the ball E has been pulled close down to the sheave, C. The floatage power of the ball, E, is such, that if the whole apparatus be immersed vertically in water, in the position of the figure, and the line be

then loosed off at F, the ball will at once float up, carrying with it a length of the line equal to the height of its ascent in the water, which will have passed under the sheaves. The application of the instrument is obvious—

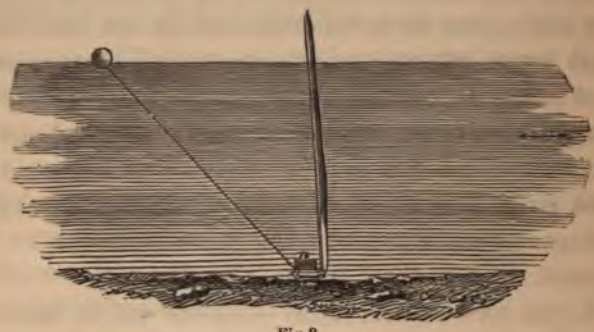


Fig 2.

The returned part of the instrument with the ball, &c. was passed under any convenient part of a casting, as in figure 2. The cord was now slacked off from the upper part of the pole as soon as it was found by view with the water telescope, or by feeling, that the ball was clear inside the rib, *n*, and the ball immediately floated up, and made its appearance, carrying the cord along with it a little way down the stream. The ball was now detached from the cord, and a half-inch rope tied to it instead, and the cord now pulled back through the little sheaves, until arrested by the rope being brought home to them. The whole "water needle" was now drawn back and pulled up, carrying the rope along with it under the casting; to this rope a chain was attached, and by it drawn through, and thus the casting was grasped so as to be lifted by suitable purchases. The operation was performed on the castings in question in the depth of winter, and with the greatest facility and success, by Mr. Edward

Toomey, one of Messrs. John and Robert Mallet's foremen, who succeeded with much ability in lifting all the castings sunk, and placing them safely on the decks of lighters again for transport to their destination.

The castings were lifted by four chains, attached to as many crabs, (or purchases) resting on two sets of skids, placed across between two lighters, moored parallel stem and stern in the rapid, by chains carried on shore, and by anchors in the stream, by which they were made quite steady.

The space between these lighters was such, and the height of the skids above the water surface was so managed, that a third lighter was dropped down the rapid, and passed in between the two moored lighters, and under the castings when raised to the highest, and from which they were lowered on to the deck of the lighter thus placed to receive them.

As the main difficulty of recovering heavy goods of large size, sunk in moderately deep water, lies in getting a grasp of them in any way, Mr. Mallet presumes, that this instrument, which so well answers the purpose, and which he believes to be new, will be an acceptable addition to the stock of engineering apparatus, and, as the inventor, he takes leave to call it the "water needle" from the peculiarity of its office.

Mr. Mallet gave a verbal account of the works in progress at the Albert Dock and fire-proof Warehouses, Liverpool, under the directions of Jesse Hartley, Esq. C.E. and described most of the peculiarities of construction in the rubble wharf walls, and modes of fire-proofing the warehouses. The communication would not admit of intelligible transcript unless illustrated by numerous engravings.

"*On an* ECONOMICAL METHOD OF FORMING ARCHES IN EXISTING WALLS;" by JACOB OWEN, ESQ. C.E. Member.

THE peculiarity of the method described by the author, consisted in making the wall itself serve as a centre, on which to turn the arch. The curve of the intended arch being struck out on the wall, a skewback was cut away on either side, and the arch being commenced, successive portions of the wall were gradually cut away, and the arch turned in cement, the wall left standing below, and serving as support for the arch while being constructed. The whole being keyed, the wall beneath was then taken away. This method had been practised with great success, to a very considerable extent, and with arches of considerable span.

[December 10th, 1844.]

CHARLES SAXTON OTTLEY, ESQ. C.E. A.M. Richmond Harbour, Longford; HENRY OWEN, ESQ. Maryborough, County Engineer for the Queen's County; and WM. FRASER, ESQ. C.E. Office of Public Works, were elected Members; and WM. FORSYTH, ESQ. C. E., and HALIDAY BRUCE, ESQ. Dame-street, were elected Associates of the Institution.

The following communications were read:—

"*On an* IMPROVED CONSTRUCTION OF THEODOLITE;" by GEORGE YEATES, Associate.

For description, see Report of Meeting, of May 27th, 1845, infra—

"*On* A METHOD ADOPTED TO RAISE A ROOF IN BALLINA;" by NOBLETT R. ST. LEGER, ESQ. C.E. Member.

Mr. St. Leger gave an account of a mode of raising a roof without removing the slates, which he had seen practised at Ballina.

The building was a stone one, with five stories, to which it was desired to add a sixth. The roof, which was a common one, was seventy feet long, and twenty-seven broad. To the ends on the heels of the rafters were attached, longitudinally, beams of timber, and vertical beams were notched to these at intervals of eight feet. These vertical pieces were let through holes cut in the floor beneath; and in them holes were bored, four inches apart; into these holes strong crowbars were inserted, and men being placed at all the bars, the roof was thus lifted above eight feet in less than half an hour, only two slates being broken during the whole operation.

[January 14th, 1845.]

THOMAS RHODES, ESQ. Engineer in chief to the Shannon Commissioners, &c.; GEORGE WILLOUGHBY HEMANS, ESQ. C.E. Inchicore; F. W. CLARENDON, ESQ. C.E. Office of Public Works, Dublin; JOHN NEVILLE, ESQ. C.E. Dundalk, County Engineer for the County of Louth; JOHN LONG, ESQ. C.E. Athlone; JOHN HILL, ESQ. C.E. Ennis; and THOS. OLDHAM, ESQ. Assistant Professor of Civil Engineering, Trinity College, Dublin were elected Members; and ROBERT JOHN HAMPTON, ESQ. District County Surveyor for County of Dublin, and ROBERT KANE, ESQ. M.D. Professor of Natural Philosophy, Royal Dublin Society, &c. were elected Associates of the Institution.

The following communication was read:—

"*On the* CONSTRUCTION OF CENTRES FOR BRIDGES;" by JOHN MAC MAHON, ESQ. C.E. Member.*

* The reading and discussion of this paper occupied the Institution during two successive Meetings, but is here referred to the latter for convenience of reference.

[February 11th, 1845.]

JOHN WM. KELLY, ESQ. C.E. Office of Public Works, Dublin; WM. T. MULVANY, ESQ. C.E. Commissioner of Drainage; M. J. FARRELL, ESQ. C.E. Galway; GEORGE WILKINSON, ESQ. Poor Law Commission Office, Dublin; and SAMUEL ROBERTS, ESQ. C.E. Ardee, were elected Members; and ISAAC FARRELL, ESQ. Great Brunswick-street, Dublin, an Associate of the Institution.

The following communication was read:—

"*On the* CONSTRUCTION OF CENTRES FOR BRIDGES;" by JOHN MAC MAHON, ESQ. C.E. Member.

THE author stated that this communication originated in circumstances connected with the erection of the new bridge over the river Shannon, at Athlone, for which he was the contractor. The bridge at Banagher had been completed, and it appeared to him that it would be a matter of economy if he could apply the centres used there, for the purposes of his contract at Athlone. The span of the arches at Banagher was 60 feet, of those at Athlone, 61 feet; and both being of the same elliptical form, it was obvious that the same centres would answer, provided their strength was sufficient. But conceiving that there had been an useless amount of strength in the centres used at Banagher, seven ribs having been used under an arch of 27 feet in length, he determined on reducing the number of centre ribs, while at the same time he increased their stiffness and strength by additional framing. He had therefore purchased from the contractor for Banagher bridge, eighteen of the twenty-one centre frames there used, and thus altering them, had used them at Athlone. At Banagher the arches were 60 feet in span, and 27 feet in length, (width of bridge) and at Athlone, as stated, 61 feet in span, and 35 feet in length;

under each arch at Banagher there had been seven centre ribs, being 3 feet 8½ inches apart, but under each arch at Athlone, there were only six centre ribs, being 6 feet 10½ inches apart.

It having, however, appeared to the principal Engineer to the Shannon Commissioners, that these frames were not of sufficient strength to bear the weight they would be called upon to support, Mr. Mac Mahon was required to satisfy the Commissioners that they were sufficient, and the present communication was the substance of his report.

In the designing and constructing of centres, the author considered that the first point of importance to investigate was the weight of the arch stones to be supported while the bridge was being built; the second, the quantity and quality of timber to be used, and the method to be adopted in the disposition of it, in order to obtain by judicious mechanical arrangements, a sufficient degree of strength, to support the insistent weight and lateral strains at the least possible expense, equilibrium being as necessary in the formation of the centres as in the construction of the arch itself; the third, to make the frame and its supports much stronger than calculation would seem to require, and in the construction to place the timbers so as to produce triangular instead of quadrangular openings.

It is known, from Rondelet, that arches can be raised until the arch joints form an angle of 30° with the horizontal, before the stones press upon the centres; from that angle to 60° the pressure on the frame is much less than the absolute weight; but from 60° to the vertex, the pressure may be assumed as equal to the whole weight. In calculating, the value of the whole pressure

on a centre frame, the effect can be ascertained with great precision, by recourse to rather a lengthy process; but for all practical purposes the rule laid down by Pitot, a celebrated member of the Academy of Sciences, in the beginning of the eighteenth century, will be found sufficiently correct: that is to take $\frac{11}{13}$ of the whole weight of the arch, for the superior 120° as the value of the pressure. For example, we find the pressure on the centres will be 444 tons, the absolute weight of the superior 120° of the Athlone arch being 565 tons; and by Tredgold's formula the pressure is shewn to be 447 tons. A knowledge of the pressure being thus obtained, the next consideration is to ascertain if props can be used, without prejudice or risk, to support the centre portion of the ribs; if they can, the construction of the frame will be rendered much more simple than when the required strength is to be obtained by trussing. Perronet tells us that oak piles, 8 or 9 inches diameter, will carry a load of 23 tons with safety; some of the oak struts used in the centres of the bridge at Orleans, sustained the enormous pressure of 2 tons on the square inch; and the American red pine props of the Ribble bridge centres (built under the author's direction) had to carry a weight of 32 tons, 18 cwt. each. The props upholding a rib of the Athlone bridge centres were seven in number, four resting on the pier footings, and three driven an average of 14 feet into the bed of the river. The four props resting on the footings, taking their power at 1000 lbs. to the square inch, are capable of sustaining a pressure of 120.2 tons; and the three driven into the bed of the river, adopting the same rule, can carry 42.4 tons each. In fixing these piles a metal ram of 11 cwt. falling 20 feet, was used, until the head of

the pile was beaten up, or until it could be driven no further.

The author considered, from his own observations, and from some experiments made by his assistant, (from which it appeared that the momentum of a body weighing 4 oz. falling through a space of 12 inches, was equivalent to a weight of 14 oz.) that a ram of 11 cwt. falling 20 feet would be equal to a pressure of about 35 tons.

In practice he had found the driven pile fully equal to the value assigned to it, but had no means of acquiring a knowledge of how much beyond the weight here stated, a pile so posited would be able to bear. From the foregoing we find that the support of one rib, viz.—the four props on the footings, and the three piles in the river, can sustain a weight equal to 225.2 tons, or nearly three times the weight they will be called upon to carry, which is 78 tons, 2 cwt. (see Table, page 79, adding 3 tons, 8 cwt. for weight of rib and lagging.) The next enquiry was as to the quantity of timber which will be required for each rib of the centres, the quality being red pine. In this part of the enquiry, he had found the following simple rule of his own formation, to answer in practice, when the centres were such as those at Athlone: Take the longest unsupported part of the beam, or in other words, the greatest distance that is between any two of the props on which the rib is to be seated, and find the weight of that portion of the arch which lies immediately above, calculating it for a breadth equal to that which the ribs are to be asunder from centre to centre, then find the scantling of a lintel supported at both ends, and having a length equal to the above mentioned longest bearing, which would support that weight, uniformly distributed over its length.

To find the weight which, when applied at the middle point of a beam supported at both ends, would break that beam, Buffon's experiments gave the following rule:—Multiply together the breadth of the beam in inches, the square of the depth also in inches, and the empirical number 651, and divide the product by the length in feet; from the quotient subtract the square of the depth multiplied by ten times the breadth, the remainder is the weight in lbs. But as a beam should not be loaded with more than ¼ the weight which would break it; also, as a beam will support twice the weight when uniformly distributed over its length, that it would support if concentred at its middle point, the following rule may be deduced from these principles, to find the depth which should be assigned to a beam, the weight which it has to carry, the length of bearing, and the breadth being given—Rule: Multiply twice the weight to be supported in lbs. by the length of the beam in feet; also from the breadth in inches, multiplied by the empirical number, 651, take ten times the length in feet, multiplied by the breadth in inches; divide the former quantity by the latter, the square root of the quotient is the depth required. On forming an estimate of several centres in comparison with the foregoing rule, it appears that the quantity of timber used in the construction of each rib is equal to that which is contained in a lintel having the same length as the girder or chord of the centres, and a depth of 2¼ times that obtained by the last rule. The application of the above rule may be illustrated in the case of the Athlone centres, thus:—The longest bearing is 12 feet, the breadth of the girder is 6½ inches, and the weight of the arch over the 12 feet bearing is 36,094 lbs.; and as Buffon's

experiments were made on oak, which he says is $\frac{4}{10}$ stronger than fir, (the timber in the Athlone centres) the weight should be taken at 50,531 lbs. to allow for the difference in strength. We have therefore–$50,531 \times 2 \times 12 = 1,212,744$; also $\overline{6\frac{1}{2} \times 651} - \overline{10 \times 6\frac{1}{2} \times 12} = 3450.5$–then $1,212,744 \div 3450.5 = 351$ and $\sqrt{351} = 19$ inches.

The girder is 56 feet long, according to the above principles, therefore, the quantity of timber required for one rib of the centres $= 56$ ft. $\times$ 42.75 in. ($= 3.56$ ft.) $\times$ $6\frac{1}{2}$ in. $=$ (.54) $=$ 107 cubic feet, whilst the actual quantity of timber contained in a rib is 101 cubic feet. In this way having obtained a knowledge of the quantity of timber required for the centre frame, it should be disposed of so as to give a mould on which the arch is to be formed, placing the scantlings, as nearly as circumstances will permit, in the direction of their greatest strength, the value of which can be easily ascertained by the principles of the resolution of forces.

The author then entered into detailed calculations to show the strength of the Athlone centres. From these it appeared that—

		Ft.	Dec.
The length of every 2° of the arch from 32° to 46°, the mean Radius being .. .. .. 10ft =		0.	348
The length of every 2° of the arch from 46° to 60° the mean Radius being .. .. 26 ft. 6 in. =		0.	924
Depth of the arch stones where the joint forms an angle of 32° with the horizon, ... =		4.	000
Depth of the arch stones, where the joint forms an angle of 60° with the horizon, ... =		3.	5

By interpolation, the depths at every intermediate 2° can be obtained, as in the second column of the following table:—

	Depth of Arch Stones.	Length of 2° of the Arch.	Constant from the Equan. W=(Sin. a-f Cos. a) P *	
32° to 34°	4.00	.348	.04	.06
36°	3.96	.348	.08	.11
38°	3.92	.348	.12	.16
40°	3.88	.348	.17	.23
42°	3.84	.348	.21	.28
44°	3.80	.348	.25	.33
46°	3.76	.348	.29	.38
Radius Changes.				
48°	3.72	924	.33	1.13
50°	3.68	.924	.37	1.26
52°	3.64	.924	.40	1.35
54°	3.60	.924	.44	1.46
56°	3.56	.924	.48	1.58
58°	3.52	.924	.52	1.69
60°	3.50	.924	.54	1.75
				11.77

* P being the pressure, W the weight of the arch stones, f the friction, and a the angle which the plane of the lower joint of the arch stone makes with the horizon. This formula expresses the relation which the pressure on the centre frame, in a direction perpendicular to the curve, bears to the actual weight of the arch stones.

The fifth column exhibits the product of the depth at every 2° multiplied by the mean length of 2° of the arch, both in feet, and by the constant, which expresses the ratio of the pressure of each 2° to its actual weight; or in other words, the value of (Sin a—f Cos a.) The sum of this column, therefore, multiplied by the weight of a cubic foot of the stone of the arches, and by the length of the arch, gives the pressure on the centre, or

$$11.77 \times 168 \times 35 = \overset{\text{lbs.}}{69207} = \overset{\text{Tons.}}{30} \ \overset{\text{Cwt.}}{17}$$

	Contents.	Weight.	Pressure.
	C. F.	T. Cwt.	T. Cwt.
Dimensions of the portion of arch from 32° to 60°. 8.75×3.75 ×35	1148	86 2	30 17
Portion of arch from 60° to crown 24.7×2.94×35	2548	192 18	192 18
	3696	279 0	223 15
For both sides, ...	7392	558 0	447 10

He next proceeded to take each timber of the frame separately, and calculated the greatest weight which could possibly come upon it in the construction of the arch, and stated the pressure which, from its dimensions, it was capable of resisting. Thus the pressure of that portion of the arch from $\sqrt{32}°$ to *a* (see Fig. 1, Pl. IV.) on one side of one rib in the centre, = 11.86 tons. Suppose this uniformly distributed over the beam, *b b*, no evil consequence could ensue, (Tredgold's Carpentry, Art 110—112, Barlow's Edit.) as the weight which would be required to break this beam = 78.4 tons, its dimensions being 13 in.×6½ in. and its length of bearing 7 feet.

Next: suppose the whole pressure, from 32° to *c*, to act at the point, *d*, this pressure is equal to 20.88 tons, and may be resolved, as shown, at (A) first into two forces, one horizontal, = 6.5. tons, and the other vertical, = 20 tons. The horizontal force is counteracted by the resistance of the principal, 3, and the diagonal, 2, the pressure in the direction of the former being 4.5 tons, and in that of the latter 3.25 tons. The vertical pressure of 20 tons is sustained by the principal, 3, the upright, 1, and the diagonal, 2 ; and if we suppose the upright, 1, to take ⅓ of this pressure, or 6.66 tons, the remaining ⅔ or

13.33 tons, will compress the principal, 3, with a force of 11.60 tons, and the diagonal, 2, with a force of 13.4 tons. Now to resist these pressures, the principal, 3, has an area of $13 \times 6\frac{1}{2} = 84\frac{1}{2}$ square inches, and would bear with safety a pressure of 37.72 tons; the upright, 1. and diagonal, 2, have respectively areas of $6 \times 6 = 36$ square inches, and $12 \times 6 = 72$ square inches, so that the former would sustain with perfect safety, a weight, tending to crush it, of 16.07 tons, and the latter of 32.14 tons.

Next suppose the pressure of the arch stones from *d* to *e* to act upon the centre, at *c*, this pressure is equal to 18.3 tons, and may be resolved, as shown at *B*, first, into two forces, one horizontal = 4 tons, and the other vertical = 18 tons. The horizontal force is counteracted by the resistance of the principal, 6, and the diagonal, 5, (not in the Banagher centres) the pressure in the direction of the former being 3.5 tons, and in that of the latter, 1 ton. The vertical pressure of 18 tons is sustained by the principal, 3, the upright, 4, and the diagonal, 5; and if we suppose the upright, 4, to take $\frac{1}{3}$ of this pressure, or 6 tons, the remaining $\frac{2}{3}$ or 12 tons, will compress the principal, 3, with a force of 12.75 tons, and the diagonal, 5, with a force of 13 tons. Now to resist these pressures, the principal, 6, has an area of 13 in. $\times 6\frac{1}{2} = 84\frac{1}{2}$ square inches, and would bear with safety a pressure of 37.72 tons; the principal, 3, has the same dimensions, and would bear the same load. The upright, 4, and diagonal, 5, have respectively areas of $13 \times 6\frac{1}{2} = 84\frac{1}{2}$ square inches, and $8 \times 6 = 48$ square inches, so that the former would sustain with perfect safety a weight, tending to crush it, of 37.72 tons, and the latter, of 21.4 tons. Next, let that portion of the arch extending from *c* to the crown, be supported by the struts, 7 and 8, the weight is 18.2 tons,

and by constructing the triangle of forces at C, we find the pressure on 7 to be 9 tons, and on 8, 13.3. tons; these timbers have each an area of 12 in. $\times 6 = 72$ square inches, and would consequently sustain a pressure 32.14 tons each. Suppose the weight of the portion of the arch, *f g*, to be uniformly distributed over *n i*, the weight is 5.36 tons and the dimensions of the timber being $13 \times 6\frac{1}{2}$ with a bearing of 4 feet, we find that it would require a weight of 13.72 tons to break it. Suppose the weight of the arch stones from *f* to *g*, to come on the centre upright, 9, the weight is 10.92 tons, the area of the upright is 13 in. $\times 6\frac{1}{2}$ in. $= 84\frac{1}{2}$ square inches, which, as before stated, would sustain a pressure of 37.72 tons.

In making the above calculations, it was necessary, in order that accidents might be guarded against, to consider each division of the frame separately, without paying attention to the assistance which that division must in reality obtain from the other parts of the rib, and thus portions of the weight which will, it is evident, act at one point of the centre, have, for the moment, been taken as acting at another; in this manner several divisions of the arch have been represented as acting more than once upon the centres—for instance, the weight of arch stones from *a* to *c* has been supposed to act first at *a*, and subsequently at *c*. This precaution is always necessary in computing the strength of such structures. It is therefore evident that if we take the sum of the pressures given in the several stages of the above enquiry, we shall have an aggregate pressure considerably above that which the timbers will be actually called upon to bear. In concluding the enquiry, a second series of calculations has therefore been made, in which the mutual assistance which the parts of the frame give to one another has been

taken into account, whereby the action of the load which each timber will have to carry has been ascertained.

These weights are given in the following table, and also the pressure which, from their scantlings, those timbers are able to bear *with safety*.

	Probable load the timbers will have to sustain	Load the timbers are able to bear.
	TONS.	TONS.
1. Upright	5.16	16.07
2. Diagonal	12. 5	32.14
3. Principal	18. 5	37.72
4. Upright	2.83	37.72
5. Diagonal	6.60	21.4
6. Principal	1.75	37.72
7. Diagonal	5.30	32.14
8. Diagonal	7.60	32.14
9. Upright	6.90	37.72
	67.14	284.77
For one rib	127.38	531.82

Thus it appears that the aggregate strength of the timbers is upwards of four times greater than the strain which will come upon them.

Similar calculations have been made for other centre frames, which appeared to the author in some degree analogous to those more immediately referred to, viz.:—the Ribble Bridge, on the North Union Railway, near Preston; the Chester Bridge, over the Dee; the Dora Bridge, near Turin; London, Conon, Tongueland, and Coldstream Bridges; and the Bridges over the River Dodder, at Donnybrook, near Dublin, and over the Barrow, at Monasterevan, the latter an aqueduct for the conveyance of the Grand Canal.

The following is a brief summary of the circumstances of these bridges:—

SUMMARY

OF THE

CIRCUMSTANCES OF THE BRIDGES AND CENTRES TREATED OF IN THE FOREGOING PAPER.

Name of the Bridge.	Where built.	River.	Span.	V Sine.	Length of Arching.	Number of Ribs.	Distance apart of Ribs.	No. of props under each rib.	Pressure on one rib.	Pressure on one prop.	Date of Erection.	Engineer.	Contractor.
			Ft. In.	Ft. In.	Ft. In.		Ft. In.		Tons Cwt.	Tons Cwt.			
Athlone	Athlone	Shannon	61 0	14 0	35 0	6	6 0½	7	74 14	10 14	1844	Rhodes	Mac Mahon
Banagher	Banagher	Shannon	60 0	16 0	27 0	7	3 8½	5			1843	Rhodes	Mackenzie
Ribble	Preston	Ribble	120 0	35 0	33 0	6	5 3½	7	230 12	32 18	1838	Vignolles	Mullins and Mac Mahon
Chester	Chester	Dee	200 0	42 0	86 0	6	5 10				1834	Hartley	Trubshaw
Dora	Turin	Dora Ripa	128 0	18 0	43 6	10	3 7	7	325 0	46 8		Moschi	
London	London	Thames	150 0	32 0	56 0	9	5 9	20	417 0	20 17	1831	Rennie	Joliffe and Banks
Conon	Dingwall	Conon	65 0	21 0	35 0	7	5 3	5	46 3	9 4	1808	Telford	
Tongueland	Kirkudbright	Dee	118 0	38 0	35 0	7	4 10	6	96 8	16 0	1806	Telford	
Coldstream	Coldstream	Tweed	60 8	20 6	25 0	5	5 4	5	45 7	9 1		Smeaton	
Aqueduct Br.	Monasterevan	Barrow	40 0	5 0	29 6	5	5 10½	7	57 0	8 3	1827		Henry, Mullins, and Mac Mahon
Anglesey	Donnybrook	Dodder	50 0	5 0	54 0	9	5 6	7	76 0	10 17	1831		Ditto

The peculiar centres used at Donnybrook, and at Monasterevan, are shown in Pl. 4, Figs. 3 and 4. They were used successfully in both places. This mode is particularly applicable to flat arches, where props can be effectively used; and as the timbers are in no way injured, and the cost of constructing is, in comparison with framing, very trivial, the system is evidently economical.

The Athlone centres had also been perfectly successful, the arches having been completed without the slightest yielding.

The author stated, that the method adopted for easing these centres was, to cut them away gradually. He had found, in the construction of the Ribble Bridge, where wedges passing laterally under three ribs had been used, that it was impossible, with all the force that could be used, to ease them; and he was therefore compelled to cut them away. He had since adopted the same plan with success in other places, and believed it was a good one.

Mr. Mallet suggested a method of easing down centering, which he thought was new, at least was so to him, and which appeared to possess several conveniences, viz:—by the use of properly prepared screw jacks, made to fit the heads of the bearing piles, or other suitable parts of the bearing frames, and used at their nearly full extent of screw to sustain the centering during the building of the arch; by slacking the screws, the centering may be eased when the arch is keyed, and in any desired ratio at given points, in a line taken in the plain of thrust.

This method also has the advantage of enabling the centering to be raised locally, in the progress of the work,

so as to correct any change of form in the centering, due to unequal loading, as in building the haunches.

The facility and smoothness of motion of screws, their bearing a load end on, and their perfect safety from slipping, are all advantages; and the cost of such a complete set of screw supports, for even the largest centering, would be inconsiderable, and the same may be used over and over again.

Fig. 1, shows a screw jack applied to the head of a bearing pile, to which a cap of cast iron is fitted, the upper end of the screw bearing against the tie-beam of the centering frame.

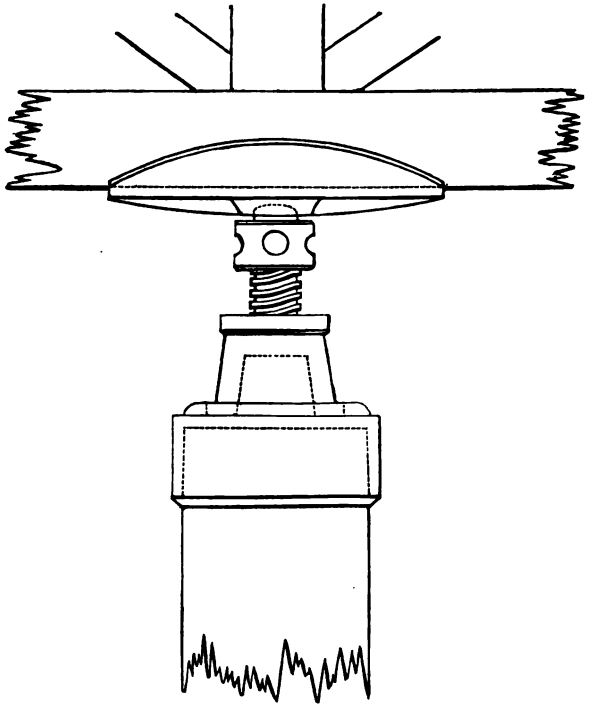


Fig. 1.

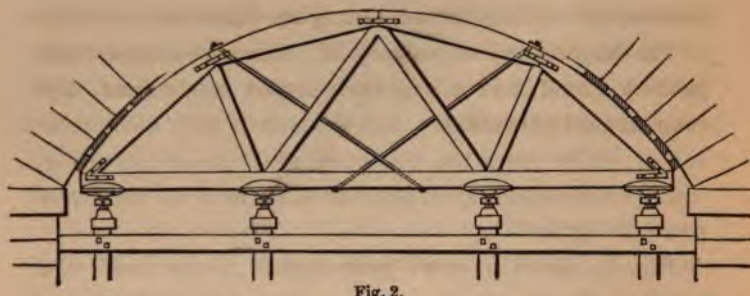


Fig. 2.

Fig. 2 shows the general mode of application to centering of moderate size, say under 40 feet span. Fig. 3 shows the way in which screws may be substituted for the chase wedges usually employed at the haunches, for easing centerings of the largest magnitude.

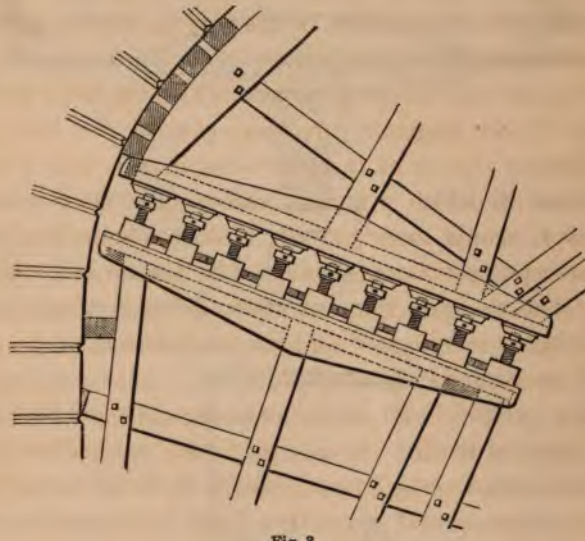


Fig. 3.

Various other conceivable modes of applying screw

bearings will at once occur to the practical man. In the construction of brick viaducts, where there are numbers of similar and equal arches, Mr. Mallet supposes this method would find a peculiarly rapid, convenient, and economical application.

[25th February, 1845.]

The following communication was read:—

"*Observations on* REGULATING WEIRS;" by WM. T. MULVANY, ESQ. C.E. Member.

THE author commenced by stating, that his wish, on the present occasion, was more to excite discussion by a brief statement of his views, than to enter into any detailed or deliberate examination of the very interesting, and, in many ways, difficult subject.

"In the wide range of subjects which the noble profession of the Engineer involves, (for in the true and legitimate objects of the profession it is noble) I know of none in which principle, rather than mere rule or precept, should more prevail. I do not mean that rule, or precept, or example should not be known and studied, but that the principles of these rules, &c. should be thoroughly investigated and known, before the rule, precept, or example was adopted.

Our pursuit, in all its branches, is, and should be, that of practical truth. Nothing will lead more directly to this than the thorough investigation of principle. Nothing leads to more fatal errors than blind adherence to rule, when the full value of the principles which formed it, is unknown or unappreciated.

If this be the case in the mere mechanical parts of the Engineer's duties, how much more so, when he has to deal with nature, (whose laws are truth itself) in some of her most subtile operations: as, for instance, in water-works, where the "truth-teller," water, tests and tries the works of man.

I must confess, to my shame, that I have studied less of books on our present subject, than I ought. I have been an anxious and watchful student of nature herself, in many of her operations, and endeavoured to trace her workings in them. But I would warn my younger friends from neglecting, too much, the study of the many excellent works that, no doubt, exist on the subject. To do so, is to labour over, as new ground, much that has long since been found out by others; but on the other hand, every thing that is read should be tested by the operations of nature, with a jealous watchfulness; and implicit faith should not be placed in what is written, without some such test. I propose, then, rather to enter into a broad general view of the subject, than to dip deeply into details.

It is well for Engineers to know, that at a very early age—in the times of Magna Charta—the necessity of guarding, from encroachment, the rivers and streams, the high-ways of the waters of the country, was felt, and all weirs were directed to be *abated* as nuisances. This became (and still exists) what is called the common law of the land on these subjects.

Then, as the wants of navigation and manufacturing power developed themselves, as the people rose from being mere agriculturists, to value the application of machinery, the right to erect such obstacles was from time to time granted; and I believe I am correct in stating, that the

common law still exists in full force in this respect, and is only controlled by the powers of Parliament, which watches with jealousy any encroachment on the common law; though, as we all know, many such works are erected at the risk of the parties, without any legal authority. Indeed, until recently, in this country, it was nobody's business to protect its rivers.

I allude to these matters to show, that for purposes of mere drainage alone, in the proper sense of the word, such erections are rarely necessary, and that this was seen early. Yet, from some vague ideas on the subject, I have often heard such works proposed as a panacea for all the evils of want of drainage, thus blindly following rule, or some example. We need only allude to the absurdity of putting an obstacle across an untouched shoal to improve drainage, to show their inapplicability in this limited sense. Their great value is, as you are aware, for maintaining a head for navigation, and water-power for manufactures and irrigation. Of course in all these observations, I allude to the fresh water parts of rivers and water-courses above the influence of the tide. I believe there are but few, if any instances, where the application of weirs across tide-ways would not be a source of evil.

The judicious application of weirs ought to be such, as, whilst accomplishing the objects sought for—maintenance of depth or head, as before—that head should not interfere injuriously with the drainage of the country, unless where the navigation or manufacture is of paramount importance, and can afford to pay for all injury done, as in cases of making reservoirs, &c. Generally speaking, I am convinced that the two objects are compatible; that is, that by the adoption of judicious

arrangements, weirs may be erected in many places to procure the maximum of manufacturing power which the locality can yield, and yet not injuriously affect the power of drainage—and the like of navigation. In some circumstances they may be made of essential benefit to drainage, as in accumulating the waters of sudden floods in natural, or even artificial reservoirs, to be given out gradually for discharge by the river courses.

Different purposes require a difference in the application of the weir and its kind. In general, at the lowest or debouching point of *lakes*, the object should be to admit of the *greatest range* in level of the water surface compatible with the objects sought: in *rivers*, except with very high banks, to admit of the *least possible range*—How often do we see this reversed.

One general principle should be maintained as regards weirs for almost any of these purposes, namely, that the passage, or approach to the weir, and from it, should be adequate to supply and carry off, at a *low level*, under maximum state of floods, the water which the weir is capable of discharging. So that under no circumstances should there be back water up to the level of the top of the weir, nor a great fall or obstacle above it, in its own proper reach, (or weir-basin, as it may be called) or under its influence; for in the latter case, instead of the weir being the outlet, the place of that obstacle would become so, and that too, from the influence of the back water from the surface of the flood over the weir. We have often seen obstructions and injuries charged to weirs, when in fact they were attributable to neglect in this respect."

Mr. Mulvany then explained what he designated as the "weir-basin," as a sufficient increase of breadth of the

river or water course above the weir, to allow of the free access of the waters to the weir, as the discharging point, and showed the necessity for depth in this space, combating the assertions often made, that the body of water on the upstream side of the weir, which is below the level of its surface, is not in motion, by exhibiting sections of rivers where great depths are attained and maintained by the current, above obstacles of this kind, and by alluding to a weir at Fermoy, where the whole of the sands and deposits accumulated at the back of the weir during low states of the river, is periodically swept over it by the floods. He also called attention to the unfinished works at Killaloe, as exhibiting, in a very satisfactory way, the necessity for depth in the "weir-basin," the shoals above the weir in that place not yet having been removed, and the consequence being a greater height of flood in Lough Derg than would otherwise exist.

The general construction, material, and position of weirs, whether formed of stone or wood, or both, and the best form of section having been then alluded to, Mr. Mulvany continued, by observing, that with reference to the controversy about short weirs placed straight across, or long weirs placed obliquely in rivers, it is presumed no advocate of oblique weirs ever gave unqualified naked opinions that oblique weirs were *per se* better than those straight across; but that such weirs being constructed in accordance with some such principle as here proposed, were best.

"The difference, as appears to me, of a great many discordant opinions that have been given on this subject, arises from the premises not having been agreed upon, or that the *discussions* arose upon *individual* cases in the *minds of each party*, in which cases the premises, or

conditions, were not similar. Such as the creation of weirs across rivers, where there *were*, or *were not*, *deposits*—where there *were*, or *were not*, *what I call* "*weir-basins*"—where an adequate power of discharge through the river to the weir did not exist; for remark, it must be *greater* than if no weir existed, always keeping in mind *the level* at which you want to obtain the discharge.

The premises properly understood, I cannot conceive a ground for argument, as to the relative power of discharge at a low level, between long weirs obliquely across, and short weirs, directly. Mr. Cubitt's familiar exemplification was good, but I prefer examples of fact."

Mr. Mulvany then described weirs at Corbally, Plassy, World's End, and Killaloe, on the Shannon, and New Haggard, on the Boyne, as it is, with a short weir directly across, and as it was, with a long weir obliquely across the river, showing the greater height to which the level of the same body of water attained in passing over the short and direct weirs.

"Some confused ideas of discharge seem to prevail, rather than the question of at what level the discharge can be obtained. Of course the water would get away, however the weir is formed.

When the supply is constant and sufficient, as in great rivers, and the object is to obtain the greatest discharge, with the least range in level, I incline to say the weir should be level on its apex, and the discharge obtained by great length. The only evil from this will be partial, namely, that arising from strong wind blowing up stream. Where circumstances do not admit of sufficient length being given, or where the expense bars the application, a remedy will be found in some of the adjuncts hereafter referred to.

Where the object is to *retard* the discharge up to a certain point, so as to keep up a supply for dry seasons, then the short weir, or the stepped, knotched, or curved surface weir, or some of the adjuncts referred to, will be applicable, having full power to discharge all surplus waters, without exceeding the maximum height which may be fixed upon.

When supplies come suddenly, as in mountainous countries, and there are no reservoirs above the site of the weir, the adjuncts referred to are of great importance."

Mr. Mulvany then enumerated several of these useful adjuncts to weirs, and described the following, by reference to plans, and the models presented to, and now in the Rooms of the Institution.

1. The Bear Trap.
2. The Syphon, with means of self-regulating.
3. Falling Boards.
4. Board to turn up stream.
5. Mallet's self-acting Circular Sluice.
6. Common Wooden Sluices.
7. Col. Blanchard's do.
8. Mr. Forsyth's self-regulating Weir for reservoirs.
9. Balance Gates.

"For gradual accumulation and discharge, perhaps none more useful or simple than the stepped or curved weir, to the construction of which Mr. Forsyth has paid much attention.

It is evident, that in order to fix the precise lengths, and other dimensions of all these engines, designed by man to regulate a strong power of nature, we must, at least, get approximate data—ascertain the maximum, minimum, and ordinary supplies—the periods after a fall of rain, in which the floods arrive at the weir, &c. &c. All these important considerations are too frequently overlooked, or

but partially enquired into. Each puts up, just as fancy or accident guides, or peculiar convenience requires, a weir, on a site perhaps accidentally selected—"it may turn out a song, it may turn out a sermon"—for which, however, must be paid, besides the expenses of construction, most probably, heavy damages, costs of law suits, and possibly disappointment in the supply of water power.

From neglect of the considerations necessary in constructing such works, many egregious errors arise, not only in old, but in new works, such as weirs on the lower part of streams being shorter than those on the upper part; and weirs on the rivers, flowing from lakes, shorter than those at the mouths of the lakes, &c. These are errors for which there is now but little excuse, less even than for those, which we have so often observed, of insufficiency of water-way in bridges.

The facilities which the Ordnance survey, and the registry of rain guages, &c. afford, for acting on better principles in future, are now well known. The grand object, however, must be to guard against evils resulting from maximum floods; the minimum discharge of water may be often preserved.

The mass of information collected, and in progress of collection, on the Shannon, is of the utmost importance towards elucidating the subject. We have there a practical guage over and above evaporation, on a magnificent scale; nor will it be wanting in information even on a minor scale, as the works on the upper parts of the river, when complete, will afford similar means for that object.

The subject of the discharge of water from the catchment, or rain-basins of different rivers, is too extensive to enter upon at present; but may form an interesting subject for future communication. I may, however, state a

few facts in illustration of this part of the subject, apprizing the Institution that a registry of the heights of water at every main point on the Shannon, has been kept since 1835, and rain guages have been lately put up at some of them.

Lough Allen near the source of the Shannon, is a reservoir of about ..... 8,852 acres,
Its catchment or rain-basin contains about ..... 93,353 ,,
inclusive of the lake, and is chiefly of a mountainous character.

The outlet from the lake is very much obstructed, and incapable of any rapid discharge, until the floods attain a considerable height. Under these circumstances the lake becomes a tolerably good measure of the quantity of rain discharged by the catchment after sudden falls of rain.

Now this lake frequently rises 3 inches in twenty-four hours, less frequently 4 inches, and sometimes 5 or 6 inches. This latter rise will be found by calculation to be equal to a film of water of more than half an inch over the entire catchment basin.

Lough Derg, above Killaloe, is a reservoir of .... 30,313 acres,
inclusive of the river up to Meelick.
The total catchment, or rain basin, of the Shannon, down to Killaloe, is about ..... 2,312,195 ,,
The immediate catchment of Lough Derg, (exclusive of that which supplies the river at Portumna) is ..... 614,161 ,,
and is formed of high or mountainous land on the west and south, and much low land on the east.

Lough Derg, before the improvements were effected, frequently rose 3 inches in a day, often 4 inches, and once in almost every year 6 inches in a day.

On the 17th November, 1840, however, it rose 1 foot in less than twenty-four hours, being equal to 50 millions of cubic yards of water. Now as the discharge at Kil-

laloe was, at least, equal to the influx at Portumna, this sudden rise can only be attributed to the supply from what I have called the immediate catchment basin of the Lough. And, over its surface, this quantity would be equal to a sheet of water of .05 feet, or more than half an inch in depth. To show that this rise was not the result of wind, I shall read the registry from the 13th to the 23rd of November, 1840.

KILLALOE UPPER SILL.

1840.	Height of water in Guage,	Ft.	In.	
Nov.	13, ...	9.	8	
	14, ...	9.	8	
	15, ...	9.	8½	
	16, ...	9.	9	Rain commenced this morning.
	17, ...	10.	9	
	18, ...	11.	1	
	19, ...	11.	3	
	20, ...	11.	4	
	21.	11.	5	
	22, ...	11.	8	
	23, ...	11.	9	

Now, had the regulating weir at Killaloe been then in existence, and suppose only 3 inches in height of water to be flowing over it, when the heavy rain fell, the surface would rise to 1 foot 3 inches, and it would take more than three days to discharge that one day's accumulation. Here we see the benefit of the lake in conserving the flood waters, and the necessity for caution, how we too freely discharge them from the lake. Here we see the absolute necessity of taking such enlarged views as will enable us to comprehend, and grasp, as it were, the operations of nature.

In the consideration of such a subject there is matter on the one hand, for humiliation, in dealing with so grand

an object, meeting so powerful an adversary—on the other, for honest, though humble satisfaction, if, comprehending the principles which ought to guide, and acting upon *them*, rather than on chance or accident, man succeeds.

[March 11th, 1845.]

MR. OLDHAM, Secretary, exhibited and described the new apparatus proposed by Mr. I. Sang, of Kirkaldy, as a substitute for the ordinary parallel plates for levelling Theodolites, &c. in which the work is performed by the use of two screws, instead of four.

[April 8th, 1845.]

ALEXANDER TATE, ESQ. C.E. District Surveyor for the County of Dublin, was elected a Member; and W. H. RANKIN, ESQ. Office of Public Works, Dublin, an Associate of the Institution.

The following communication was read :—

"*A descriptive notice of the* ARCHIMEDEAN RAILWAY;" by ISAAC FARRELL, ESQ. Associate.*

THE author stated, that his attention had been first directed to the subject, in the beginning of the previous year, and with particular reference to Ireland, considering that the amount of traffic in this country would not repay the great expense of construction on the ordinary loco-

* This communication was illustrated by a well executed working model, on a scale of half an inch to the foot, showing the several arrangements proposed.

motive system. He also thought any system which would, by means of stationary engines, combine economy of construction with economy of locomotion, while the profiles of the lines might more nearly assimilate to the natural surface of the country than on the ordinary system, would prove of great advantage.

By the "atmospheric" system some of these advantages, were obtained, but the objection on the ground of first outlay remained undiminished, and the decrease in expense of locomotion had not yet been satisfactorily established. The author's first idea was somewhat different from that now proposed, but the endless screw formed a part of it, and it then occurred to him to enlarge the screw, and make it the conductor of power to the trains; and after practical investigation, and the benefit of Mr. Mallet's aid in devising the best mode of connecting the shafting, &c. he had determined on the plan then before the Institution.

He had given the name Archimedean, from the strong resemblance which it had to the original water engine of Archimedes, viz.—a tube coiled spirally round a cylinder.

"But as a cylinder of the dimensions necessary for my purpose, would be expensive and cumbrous, I have substituted a comparatively small shaft, averaging not more than 4 inches in diameter of iron tubing, and the spiral, or thread of the screw, which corresponds with the tube in the water engine of Archimedes, I support by means of a series of arms or spokes, keyed on this shaft, or otherwise properly secured to it, and to the ends of which the spiral is firmly bolted. The diameter of the spiral, or screw propeller, I propose to be from 18 to 24 inches, but it may be more or less; the greatest length, therefore, of those arms will not exceed 10 inches. The form I think best for them is a flat bar, which may be of half-

inch wrought iron, from 2½ to 3 inches broad at the base, and tapering to about 1½ or 2 inches at the point, where it is bent to an L shape, and bolted to the spiral. The spiral is proposed to be a bar of rolled iron, H shaped, that is, a flat bar, with a top and bottom flange: this shape would give great security and strength, combined with lightness. The shafting is to be in lengths of from 12 to 15 feet. The model is formed in lengths that represent 13½ feet, which admit of a revolution and a half of the screw, with a 9 feet pitch in each length, which pitch would be equal to an inclined plane of 2 perpendicular to 3 horizontal. These lengths of shafting are connected by couplings, which obviate any effect that might be produced by accidental sinking of the rails, and which will allow the shafting to be laid on the quickest curves that are advisable on railways, (the model describes a curve with a radius of 600 feet.) The bearings are turned, and rest on metal saddles, bolted down to the cross sleepers of the railway; by allowing these bearings to rest between friction rollers, the shafting need not be reduced at the bearing points, and the friction may be reduced to a very small part of the ordinary calculation. The screw-propeller is laid down in the centre of the track, and caused to revolve on its axis, by steam or any other power communicated to it; and when thus revolving, the spiral rail presses against a pair of wheels that are attached to the frame of the leading carriage of the train, one wheel being at either side of the axis of the screw; and which are so arranged, that while one wheel is pressed forward by the thread of the screw, as it revolves, and thus carries the train with it, the other wheel acts as a check by pressing against the spiral on the other side of its axis, and prevents the train from moving with an unequal or

accelerated motion, and aids in giving a revolving motion to the screw. When the motion of the screw-propeller is reversed, for the purpose of bringing the train back, that which was the propelling wheel before, becomes the check wheel, and that which was the check wheel becomes the propeller. These wheels are perfectly under the control of the conductor, who can, by turning a lever handle, disengage them in a moment from the propeller, and by the same means apply the break to the bearing wheels.

Each wheel is suspended by parallel jaws, that carry its axle bearings; these jaws turn in centres at the top, which permit them to be raised up when the wheels are to be disengaged from the screw. They are raised by means of connecting rods, attached by centres to the jaws of the wheel and to the lifting apparatus above; the latter consists of a vertical screw turned by the lever referred to, and on which a travelling nut runs; to this nut a cylinder is attached, that has a flange round the lower end; upon this flange rests the cross beam, to the ends of which the connecting rods, by which the wheels are raised, are attached by centres; this cross beam is bored to fit the cylinder, and a spiral spring on the outside of the cylinder presses on this cross beam. The use of this spring is, while it has sufficient power to keep the wheels in contact with the propeller, it permits them to rise up with any sudden shock; and if they should be thus thrown off the propeller, or if at any time they should be let down in an improper place upon it, there is a lateral spring on the outer jaw of the frame of each wheel, that presses against the end of its axle, and permits it to yield in the line of its axis, when the spiral of the screw, comes in contact with the side, instead of the face

of the wheel; and then having allowed the spiral to pass, the wheels will instantly adjust themselves upon it, in their proper places.

When the conductor wants to stop the train, he turns the handle of the vertical screw; and when the propelling wheels are lifted up so as to clear the spiral, the travelling cylinder or nut, from the bottom of which the connecting rods are suspended, has reached a second cross beam, which is attached, by means of connecting rods, to a lever on the axle of the break, and by continuing to turn the handle, he presses the break, in the ordinary way, against the periphery of the bearing wheels; by this contrivance the break cannot be applied to the bearing wheels, until the propelling wheels have been disengaged from the screw.

Thus far my invention is applicable to any existing railway; the screw could be laid down in the centre of the track, and the propelling wheels attached to as many of the carriages as might be deemed necessary to form leading carriages."

The model also embraced another improvement mentioned in the specification: "The wheels are without flanges, and there is a pair of friction rollers at each end of the carriage, attached to the under frame in the line of the axles of the bearing wheels; these friction rollers run on each side of a central guide rail, that rests on, and is firmly secured to the apex of the triangular bearing saddles, which also support the screw-propeller. This guide rail may be of wood or iron, but is at present proposed to be of iron tubing, in lengths corresponding with the lengths of the shafting, and screwed into sockets cast on the apex of the bearing saddles; it is proposed to be about 4 inches diameter, which I calculate will be more

than sufficient to resist the centrifugal force of a train passing round the quickest curves.

The advantages I expect to be derived from this invention are—economy in construction, economy in power for locomotion, and facility for transmitting frequent trains with perfect safety.

1st.—As to economy of construction:—As the screw-propeller will be equally effective on an incline as on the level, the lower and higher levels of the country may be preserved, and united by short inclined planes; and all deep cuttings and high embankments avoided, and a proportional saving effected in bridges, viaducts, &c. The rails not having more than one third of the weight of the locomotive inpinging upon them, may be reduced to at least half their present weight; and a considerable saving may be made in the iron work of the carriages, they not having the weight of the locomotive and heavy trains to resist; the expenses of turn-tables, workshops, and watering stations will also be avoided. The saving in construction may therefore be calculated at about £2000. per mile, when compared with a railway on the locomotive system; and at £3000 per mile of single way, as compared with the atmospheric principle.

2ndly.—With respect to the economy of power:—The Archimedean system affords peculiar facilities for the transmission of trains at short intervals, with perfect safety, and without increasing the locomotive power. Thus, by sending off at ten minute intervals, light trains, not exceeding 20 tons each, or not more than the weight of the present locomotive engine and tender, a traffic, exceeding ten thousand passengers per day, could be carried on, by stationary engines, not exceeding ten horse power per mile, and at less than one fourth of the cost of the present locomotive or atmospheric systems."

[April 22nd, 1845.]

The following communications were read :—

"*Observations upon the Tidal Action, in the Estuary of Ballyteigue, in the County of Wexford;* by WM. FRASER, ESQ. C.E. Member.

THE Estuary of Ballyteigue, or, as it is locally termed, Ballyteigue Lough, lies at the back of a narrow range of sand hills, stretching from east to west, for about seven statute miles, and which are from 20 to 60 feet above the level of the sea, at low water. At the western extremity of these sand hills, the estuary is connected with the bay by a narrow channel, which, where it enters the sea, is obstructed by a bar, composed principally of fine sand, and upon which, at low water of ordinary springs, the depth is about 12 inches.

The form of this lough is such as would lead one to suppose that great irregularities existed, not only in the time of ebbing and flowing of the tides, but also in their velocity and height at different parts of the estuary. At the entrance from the sea, the width of the channel, at low water of ordinary springs, is 150 feet, at high water about 300 feet. Up to the site of the proposed embankment (about 3¾ miles from the bar) the average width at low water is about 400 feet, and at high water it increases from 400 to 1400 feet. From this point, to "Ring's Nook," (see Plate 5) about 6¼ miles from the bar, the low water channel is not more than 20 yards wide, but the space covered at high water of ordinary springs, suddenly enlarges to nearly a mile in breadth.

At "Ring's Nook," the high water channel is contracted to about 900 feet, but it immediately widens again, and

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forms the "broad water," which, though very shallow, is a permanent lake, the tidal and fresh water being prevented from flowing out by a bar across the channel at "Ring's Nook." The northern extremity of the "broad water" is about 8½ miles from the bar, but the influence of the high spring tides extends up the "Mayglass" river for about a mile further. Thus, to take a general view of the estuary, we find it to consist of—first, a narrow channel communicating with the sea, and nearly four miles in length; then a sudden expansion for about two miles, when it is contracted for the space of a few yards, and again expands for about two miles, and in a direction, nearly at right angles to the former. The extent of the whole basin, filled at high water of spring tides, is about 2200 statute acres; of which 600 lie between the bar and the site of the proposed embankment.

In May, 1843, I made (in conjunction with Mr. Russell) some observations upon the tides of this estuary; and subsequently, in April, 1844, I was enabled to observe them more extensively. The results of the observations made at these separate periods, agree so nearly, that we may look upon them as being tolerably accurate.

In the Bay of Ballyteiugue, the rise of ordinary spring tides is 11 feet, of neap tides, 6 feet, and of extraordinary springs, about 14 feet.

Of the many spring tides observed, we will, in order to avoid confusion, take that of the 30th May, 1843, as an illustration. On that occasion it was high water in the bay, at six o'clock, A.M.; and the whole rise of tide was 10 feet. Under certain circumstances of form and extent, which, perhaps, are seldom, if ever, found to exist in nature, this tide would have risen to the same height throughout the whole estuary; and whatever pe-

culiarity may be found to exist in the tidal action, must be chiefly, if not altogether, attributable to the form and size of the receiving basin. We shall see how this is illustrated, by the actual circumstances of the case before us.

At the Coast Guard station, not more than 300 yards from the bar, we found the level of high water to be nearly 18 inches lower than the high water in the open sea. At the distance of two miles from the bar, it was 1 foot 9 inches lower; at "Ring's Nook," (6¼ miles from the bar) it was 2 feet 8 inches lower; and upon the other side of "Ring's Nook," in the "broad water," it was 3 feet lower than the level of high water at the bar.

I have already said it was high water at the bar at six o'clock; on the lower side of "Ring's Nook," it was high water at 8h. 8m. or two hours and eight minutes later; and in the "broad water," the time was nine o'clock, or three hours later than the time of high water at the bar. Thus at the same time that it was high water at "Ring's Nook," it was half ebb at the bar; in fact, from the time it begins to ebb at the entrance, the time of high water at any part of the lough is determined by the progression of a wave up the estuary, from the apex of which there are two currents; one towards the sea, forming the ebb tide, and the other towards the "broad water," forming the flood tide. As the apex of this wave, very soon after it enters the estuary, falls to a level of from 18 inches to 2 feet below that of high water in the open sea, the curious anomaly occurs of there being at the bar a strong current into the estuary, while at the same time and place, the tide is descending. And this leeward current continues until the sea has fallen to the level of the tidal wave in the estuary, when the waters remain still for a

few minutes, and then slowly begin to flow out. I would again refer to the great difference between the time of high water on each side of "Ring's Nook;" the distance is only a few yards, yet the difference of time is 52 minutes. This, when first observed, surprised me much; but when we consider the greatly enfeebled action of the flood tide when it reaches "Ring's Nook"—that here it is also turned into a new direction, and that it has to contend with a very strong current running out of the "broad water," the difference of time, will, I think, be accounted for.

At low water an effect takes place similar to that which we have observed at high water; for the time and level of low water at any part of the estuary will be the time and height at which the flood tide can overcome the current of ebb. Thus, as high water is governed by the progression of a wave up the estuary, from which there are two currents, one each way; so is the time of low water regulated by the progression of a corresponding hollow, towards the centre of which there are two currents, one from the sea, the other from the estuary. The time and height of true low water will always be in advance of the apparent flood tide, for besides the advantage of its superior momentum, the lesser specific gravity of the effluent water will cause it to float on the surface, and thus it will appear to be falling, while it is actually rising. This fact is particularly observable at the bar. Out of many observations I shall choose one, taken on the 25th of April, 1844:—It was low water on the bar, at half past three o'clock, A.M. At this time there was a very strong current out to sea, which continued until five o'clock, (one hour and a half) at which time the flood tide had risen 15 inches.

These remarks may perhaps render less obscure the actual observations made on the 30th May, 1843, on the low water of the tide before alluded to. It was low water on the bar at eight minutes after noon. At the coast guard station the time was twenty-five minutes after noon, and the water's surface was 1 foot 3 inches higher than the level of low water at the bar. One mile and a quarter from the entrance, the time was one o'clock, and the height 2 feet 6 inches above the level of low water at the bar. At the site of the proposed embankment, the time was two o'clock, and the height was nearly the same as that last stated. At "Ring's Nook," the time was 3h. 25m., and the height 4 feet 4 inches above the low water at the bar. In the "Broad water," the tidal action is at all times so feeble as to render it difficult to tell the precise time of low water; but on this occasion its height was 6 feet above the level of low water in the open sea. Thus we find in the line of low water during springs, a rapid fall at "Ring's Nook," (1 foot 6 inches in a few yards,) occasioned by the bar before alluded to. From "Ring's Nook" to the proposed embankment, the fall is one foot in a mile: it then assumes a nearly level surface to within a mile of the bar, whence it descends to the sea, with a fall of 2½ feet in a mile. During neap tides the effects are very different from those produced during springs. The heights of high and low water, as well as the time of flood and ebb, assimilate more nearly to those in the open sea. This is occasioned by the fact that neap tides never enter the "Broad water," nor rise over the extensive mud banks; so that, with the exception of the narrow channel up to "Ring's Nook," we may look upon the neap tide basin as terminating at the site chosen for the proposed embankment. I will state the result of one

observation :—On the 21st June, 1843, during neap tides, I found the high water, at the site of the proposed embankment, to be 7 inches, and at "Ring's Nook" only 13 inches, lower than the level of high water at the bar. More numerous observations showed the surface of this tide to have assumed a nearly uniform incline, falling from the bar to "Ring's Nook," at the rate of about two inches in a mile. When comparing the effects of spring and neap tides, there is one fact so singular, that I cannot pass it unnoticed, namely, that about "Ring's Nook," and for some distance down the channel, not only is the low water of neap tides lower than that of springs, but the low water of springs is nearly as high as high water of neaps. This will be easily understood, when we reflect that the waters of spring tides must be drained out of the broad lough, and off the extensive slob which they cover to about fifteen inches in depth. Thus, before they have time to fall to a low level, they are arrested by the succeeding flood tide, and this heaping up of the waters continues until the neap tides set in, when, as before stated, the tides in the estuary begin to assimilate to those in the open sea.

There is another effect of the tide to which I should wish to draw your attention—I allude to the abrasion of the shore of the estuary near the entrance from the sea. That the opening is shifting its position westward, is a circumstance of common observation to those who reside upon the coast. Captain Vetch, who, in 1840, reported upon the reclamation of the tide lands on this coast, states, that he was informed the rate of corrosion westward was eight feet per annum. This corresponds with my own observation upon the changes produced between May, 1843, and May, 1844. The name of the bar also

bears witness of its having shifted its position, it is called the Bar of "Lough," from its having once been opposite to a townland of that name, bnt which is now situate three quarters of a mile up the estuary; and it is probable the opening will continue to shift its position, until arrested by some rocks which lie about half a mile to the west of the present entrance.

Before closing this part of the subject, I would draw your attention to the striking analogy there exists between Ballyteigue Lough and almost every other estuary upon this coast. They are nearly all separated from the sea, by similar ranges of sand hills, evidently formed by the action of the tidal currents, whilst their entrances are confined, and, for the greater part, shifting.

We now come to consider the probable effect the proposed embankment will produce upon the tides of this estuary. It is, I think, clear, that the present spring tide basin is too large to be filled and emptied through its present entrance during one tide; hence the great irregularity in the time and height of flood and ebb, compared with those in the open sea. We therefore presume, that by diminishing the basin to the extent it has at neap tides, it will be filled and emptied by each tide in nearly the regular time of flood and ebb; and that, by deepening a few shoals lying between the proposed embankment and the bar, the tides will rise and fall to nearly the same level as in the open sea. Should this be the result, the total quantity of water entering the estuary, will be very little diminished. The quantities would stand nearly thus:—The whole quantity which at present flows in during spring tides is about 163,000,000 of cubic feet. Of this quantity 73,000,000 are spread over the space between the bar and the proposed embankment. By the

increased height to which we calculate the tides will rise, and the increased depth to which they will fall, an additional quantity of tidal water, equal to 68,000,000 of cubic feet, would flow in, making the future total quantity less than the present, by about 22,000,000 of cubic feet. What effect these altered circumstances of the estuary may have upon the bar it is difficult to say; but I trust the time is not far distant when we shall be able to state what they have been; and whether the result will be such as we now confidently anticipate, or whether our expectations will be disappointed, at least one fact will have been added to guide us in our reasonings upon a subject so interesting to the profession.

"*On the drainage and improvement of Ballyteigue Lough;*" by W. T. Mulvany, Esq., C. E., Commissioner for Drainage, Member.

Mr. Mulvany gave an account of the plan proposed by the Commissioners for Drainage, for the improvement of Ballyteigue Lough in the County of Wexford. He described, by means of large plans, its peculiar features, and detailed the several methods which had been proposed for its improvement. Some years back, Captain Vetch had reported on this, as well as some similar estuaries in the Co. of Wexford, to a company who were anxious to undertake the enclosure and reclaiming of the flooded lands. His plan consisted mainly in turning the discharge of the waters of the several streams, falling into the lough, into a new course, to be formed near Crossfarnoge point, (see Plate V.) and embanking across their present channel. In this plan no regard whatever

was had to the navigation of the tidal estuary which exists at present; the only object sought being the recovery of the slob lands. Subsequently the attention of the proprietors in the neighbourhood having been excited by the interest which others, unconnected with the locality, evinced, several plans had been proposed. Among others, Sir John Macneill had recommended a plan somewhat similar to that of Captain Vetch, but having some slight regard for the navigation of the tidal lough. At this time application was made to the Drainage Board to undertake the matter, as being a party not likely to be influenced by local or personal interests; and consequently the whole lough had been carefully examined by Mr. E. Russell, with the assistance of Mr. Fraser, and an able report had been made on the subject. Mr. Fraser had subsequently made a series of observations on the tides, the results of which he had detailed himself, and the entire plans had been again revised by Mr. MacMahon. The plan proposed consisted chiefly in forming an embankment across the estuary, in such a position as should not interfere with the present navigation; and which, while it confined the tidal action to a smaller space than at present, would still admit such an amount of tidal water, as could again be discharged, during the ebb, in about equal time. The great objection at present was the much longer continuance of the ebbing of the tide than the flowing, a difference amounting to nearly two hours. It was also proposed to make a new cut, through which there should be a tidal navigation as far as Bridgetown. [Mr. Mulvany fully explained the several parts of the plan proposed, and pointed out on the plans the different parts; but it would be impossible to make his descriptions intelligible without the aid of maps and sections.] The

matter was still undecided, as in all cases where a navigation was concerned, the sanction of the Admiralty was necessary, and the plans had been laid before them. Some of the parties who considered that they would be injured, had petitioned the Admiralty not to sanction the project, and Mr. Cubitt had been sent over to examine into, and report on the matter.

[May 13th, 1845.]

The following communication was read :—

"*An investigation of some formulæ for finding the maximum amount of resistance required to sustain banks of earth, or other materials, and the position of the fracture requiring that resistance:* by JOHN NEVILLE, ESQ. C.E. M.R.I.A. County Surveyor of Louth, &c. &c. Member.

IN cuttings and embankments, it will often be found of advantage, particularly where quarries or stones are convenient, to cut off the toes, G, D, C, Figs. 1 and 2, of the

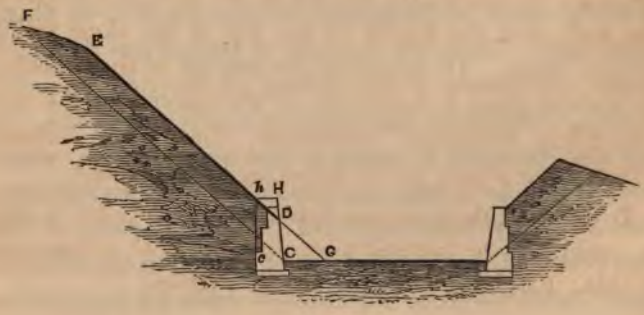


Fig. 1.—Section in cutting.

slopes, and build retaining walls instead, technically termed dwarf walls. The advantages to be gained by this proceeding, are: first, the dwarf walls answer for fences; secondly, the quantity of land required for work to be executed, is lessened; thirdly, the quantities of earth-work are much reduced; and fourthly, the toes of the

Fig. 2.—Section in Embankment.

slopes are neatly defined, and also protected and rendered permanent, a precaution particularly necessary in districts where swine or cattle abound.

In order to determine the dimensions for dwarf, or other retaining walls, it is first necessary to determine the pressure to which they are subjected. This will depend on the slope proceeding from the top of the wall, the angle of repose, the gravity of the stuff, the height of the wall, and the height of the top of the slope within certain limits. To determine the amount of the pressure, its amount when a maximum, or the amount of the corresponding horizontal resistances, that would balance either, is the object of the following investigations.

To determine the horizontal resistance or R, required to keep in equilibrium the fractured piece, B,F,C,D, of an embankment or bank; B,F, being horizontal, and D,C, vertical.

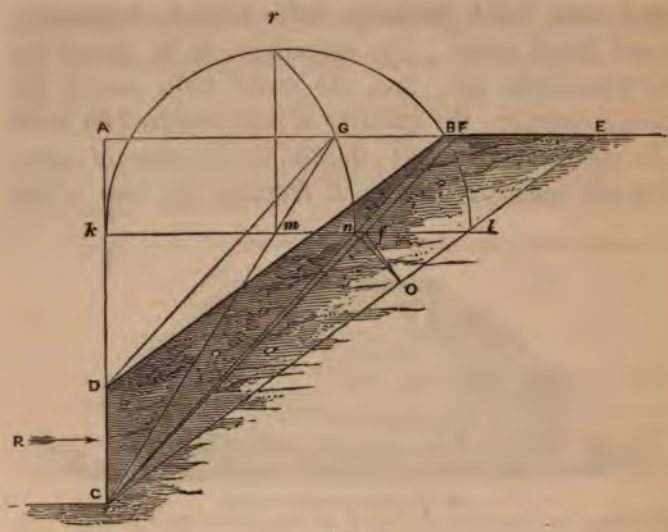


Fig. 3.

Produce BF, and CD, to meet in A: put the angle, ADB $= \theta$ the angle, ACF, $= \varphi$; AC, the whole height from the bottom of the fracture to the top $=$ H. CD, the height of the bank above C, at the back of the dwarf wall $= h$, then we get the triangle, A,D,B, $= \frac{(H-h)^2 \tan. \theta}{2}$, and the triangle, A,C,F $= \frac{H^2 \tan. \varphi}{2}$

Hence, B,F,C,D $=$ A,C,F—A,D,B $= \frac{H^2 \tan. \varphi - (H-h)^2 \tan. \theta}{2}$

Putting f for the friction of the stuff, and W for the weight of a cubical foot, we get, by the property of the inclined plane, taking friction into account,

$$R = W \times \frac{H^2 \tan \varphi - (H-h^2) \tan. \theta}{2} \times \frac{1 - f \tan. \varphi}{f + \tan. \varphi} \qquad (1)$$

When R is a maximum the differential of (1) is equal to nothing: by differentiating putting $m = \left(\frac{H-h}{H}\right)^2 \tan. \theta$, and making a few reductions there results

$$\tan.^2 \varphi + 2 f \tan. \varphi = f\, m + \frac{m}{f} - 1 \qquad (2)$$

Now putting A,C,E, the complement of the angle of repose = c, $\frac{1}{\tan. c} = f$, as may be easily shown, therefore by solving the quadratic equation (2) and substituting this value for f, there results for the value of φ when R is a maximum

$$\tan. \varphi = \frac{\sec. c \sqrt{m \tan. c + 1} - 1}{\tan. c} \qquad (3)$$

Restoring the value of m there also results

$$\tan. \varphi = \frac{\sec. c \sqrt{\left(\frac{H-h}{H}\right)^2 \tan. c + 1} - 1}{\tan. c} \qquad (4)$$

Join C and B, draw DG, parallel to CB and join G and C. It is evident the triangle, A,C,G = the triangle, A,D,B, and also that the triangle, C,G,F, = C,D,B,F; putting therefore the angle, A,C,G, = b, there results $(H - h)^2 \tan. \theta = H^2 \tan. b$ and hence $\tan. b = \left(\frac{H-h}{H}\right)^2 \tan. \theta = m$: therefore equations (3) or (4) become

$$\tan. \varphi = \frac{\sec. c \sqrt{\tan. b \ \tan. c + 1} - 1}{\tan. c} \qquad (5)$$

Now in equation (1) $\frac{1 - f \tan. \varphi}{f + \tan. \varphi} = \frac{\tan. c - \tan. \varphi}{1 + \tan. c \tan. \varphi} = \tan.(c - \varphi)$ by trigonometry; hence this equation becomes

$$R = \frac{H^2 W}{2} (\tan. \varphi - \tan. b) \times \tan. (c - \varphi) \qquad (6)$$

By substituting the value of tan. φ in (5) for the maximum value of R, and making a few trigonometrical reductions, there results for this value

$$R = \frac{H^2 W}{2} \left(\frac{\sec. c - \sqrt{\tan. b \tan. c + 1}}{\tan. c}\right)^2 \qquad (7)^*$$

but $\tan. b = \left(\frac{H-h}{H}\right)^2 \tan. \theta$ hence

$$R = \frac{H^2 W}{2} \left(\frac{\sec. c - \sqrt{\left(\frac{H-h}{H}\right)^2 \tan. \theta, \tan. c + 1}}{\tan. c}\right)^2 \qquad (8)$$

* For other forms of this equation see (31) (32) and (33.)

It is therefore evident that the resistance required in a dwarf wall at DC, is equal to the resistance required for a wall facing C,G, having the vertical height, H, and an inclination from the vertical, b, such that $\tan. b = \left(\frac{H - h}{H}\right)^2 \tan. \delta$.

When $H = h$, $\tan. b = 0$, C,D,B, coincides with C,A, and equation (5) is reduced to

$$\tan \varphi = \frac{\sec. c - 1}{\tan. c} = \tan. \tfrac{1}{2} c \qquad (9)$$

which is the equation of Prony: and (8) or (9) becomes in the same case

$$R = \frac{H^2 W}{2}\left(\frac{\sec. c - 1}{\tan. c}\right)^2 = \frac{H^2 W}{2} \times \tan.^2 \tfrac{1}{2} c \qquad (10)$$

By subtracting the value of the $\tan. \varphi$ in (5) from $\tan. c$

$$\tan c - \tan \varphi = \frac{\sec. c \times (\sec. c - \sqrt{\tan. b \tan. c + 1})}{\tan. c} \qquad (11)$$

and by trigonometry and reduction,

$$\tan. (c - \varphi) = \frac{\sec. c - \sqrt{\tan. b \tan. c + 1}}{\tan. c \sqrt{\tan. b \tan. c + 1}} \qquad (12)$$

By comparing (7) and (11)

$$R = \frac{H^2}{2 \sec.^2 c} \times (\tan. c - \tan. \varphi)^2 \qquad (13)$$

another expression for R, but requiring φ to be first determined.

Equation (11) furnishes the following geometrical construction for finding C,F, and hence the angle, φ, or $c - \varphi$ by measurement. From any point k in AC, draw k, m, l, at right angles, to AC, cutting CG, the equating line, and CE, the line of repose, respectively, in m and l. On kl describe a semicircle, and raise mr at right angles to k, l, meeting the circumference at r; from k, as centre, with kr, as distance, describe an arc to cut kl in n; from C, as centre, with C, n, as distance, describe an arc to cut C l in o; from o raise of, at right angles to CE, meeting kl in f, join C f, and produce it to F, then C,F,B,D, or C,F,G, requires a greater horizontal resistance than any other fracture, except CF, can give. For $kn = \sqrt{\tan. b \tan. c}$; $Cn = \sqrt{\tan. b \tan. c + r^2} = Co$; $\frac{Cl \times lo}{kl} = lf = \tan. c - \tan. \varphi$

Again, put the angle, B,C,A, $= a$, then $\frac{H - h}{H}$ tan. $\theta =$ tan. a and the point, F, coincides with B, tan. a = tan. φ; hence in this case we have from equation (4) and the above,

$$\frac{H - h}{H} \text{ tan. } \theta = \frac{\text{sec. } c\sqrt{\left(\frac{H - h}{H}\right)^2 \text{tan. } \theta \text{ tan. } c + 1} - 1}{\text{tan. } c} \qquad (14)$$

from the solution of which, after some easy trigonometrical substitutions, we have

$$\left.\begin{aligned} \frac{H - h}{H} &= \frac{\text{sec. } c\sqrt{\text{tan. }^2\theta - \text{tan. } \theta \text{ tan. } c} - \text{tan. } \theta}{\text{tan. } c\ (\text{tan. }^2\theta - \text{tan } \theta \text{ tan. } c) - \text{tan. } \theta} \\ &= \frac{\text{sec. } c\sqrt{1 - \frac{\text{tan. } c}{\text{tan. } \theta}} - 1}{\text{tan. } c\ (\text{tan. } \theta - \text{tan. } c) - 1} \end{aligned}\right\} \qquad (15)$$

an equation that will give the relations of H and h, so that the fracture requiring the maximum resistance may pass through B.

When $\theta = c$

$$\frac{H - h}{H} = 1 \qquad (16)$$

where H must be infinity, or $h = o$. consequently the fracture becomes parallel to the face, which is also evident from (4). from which results

$$\text{tan. } \varphi = \text{tan. } c.$$

As tan. $a = \left(\frac{H - h}{H}\right)^2$ tan. ^2c: in this case (8) becomes

$$R = \frac{H^2W}{2} \left.\frac{\text{sec. } c - \text{sec. } a}{\text{tan. } c}\right|^2 \qquad (17)$$

and where H is infinite, this can be shown to become

$$R = \frac{h^2W}{2} \text{ sin. }^2c \qquad (18)$$

This is evidently the greatest value that R can attain in slopes, standing at the angle of repose, or at a flatter angle. Comparing (10) with (18)

Resistance in (10) : Resistance in (18) : : tan. $^2\frac{1}{2}c$. sin. ^2c (19)

If the angle of repose is 34° which nearly corresponds with a slope of $1\frac{1}{2}$ to 1, $c = 56°$

$$\tan.^2 \tfrac{1}{2}c : \sin^2 c :: \overline{532}|^2 : \overline{829}|^2 :: 283 : 687 :: 3 : 7 \text{ nearly.}$$

Hence, in this case, for the same height of face, h, the resistance required when the bank slopes from the top of the wall, at or under the angle of repose, can never exceed the resistance, when the top is horizontal, derived from the equation of Prony, in a greater ratio than from 7 to 3, whatever the length of the slope may be, and whatever the height to the top.

If the angle of repose is 45° or a slope of 1 to 1

$$\tan.^2 \tfrac{1}{2}c : \sin.^2 c :: \overline{414}|^2 : \overline{707}|^2 :: 171 : 500 :: 1 : 3$$

nearly, for the ratio in this case.

When $C = 90°$ as in fluids, $\tan. \frac{1}{2} c = \sin c = 1$, the ratio is one to one, or that of equality; and when $c = 0°$ or nearly so, $\overline{\tan. \frac{1}{2} c}|^2 : \overline{\sin. c}|^2 :: \overline{\sin. \frac{1}{2}c}|^2 : \overline{\sin c}|^2 :: \overline{\frac{1}{2} c}|^2 : c^2 :: 1 : 4$, which gives the extreme limit, the ratios lying between 1 to 1, and 1 to 4.*

* In the Philosophical Magazine, Vol. 51, p. 402, TREDGOLD, taking into consideration the friction at the back of the wall, concludes a paper on the value of R in these words:—"According to the principles I have endeavoured to point out, it appears, that when the earthen scarp exceeds the height, h', it might be resisted to any height without increasing the pressure against the wall, as is indicated by the experiments of COL. PASLEY. But if we suppose (with Belidor, Rondelet, &c. &c.) that the angle of fracture coincides with the natural slope of the earth; and also that the inclination of the earthen scarp is the same as the natural, (which is generally taken at 45°) it is obvious the pressure ought to increase with the height of the earthen scarp, *without limit.*" It is, however, evident that Tredgold was mistaken in this conclusion, for even rejecting the friction at the back of the wall, it is here shown, that the limit of resistance required, compared with the resistance when the top is horizontal, can never exceed the ratio of 4 to 1, and when the scarp is that taken by Tredgold, the ratio cannot exceed 3 to 1. Hereafter the subject of friction at the back of the wall shall be considered generally; but to take the amount of that friction the same as the friction of the earth in the bank, and to solve the question accordingly, is but solving a particular case, and this solution is only perfect, for a vertical face, and horizontal top, in the work quoted from.

Equations (4) and (8) give the values of φ and R for dwarf walls, to the face, CD, Fig. 4, and equations (5) and (7) the values of φ and R, for sloping walls to the face, C,G. Fig. 5, and though it has been supposed, at the commencement of the investigation, that CD and CA were perpendicular to the horizon, and AE, parallel to it, the investigation given also holds good when CD and CA are perpendicular to AE, whatever the inclination of these lines to the horizon may be, the same notation being preserved; that is CD $= h$, CA $=$ H, ACG $= b$ &c., in Figs. 6 and 7; c being here taken as the angle, A,C,E, between the line of repose, CE, and the perpendicular, CA, $=$ H, to AE, and not the complement of the angle of repose. For in equation (1) tan. ECF, $=$ tan. $(c-\varphi) = \frac{1+f \text{ tan. } \varphi}{f+\text{tan. } \varphi}$ continues true for Figs. 6 and 7, as well

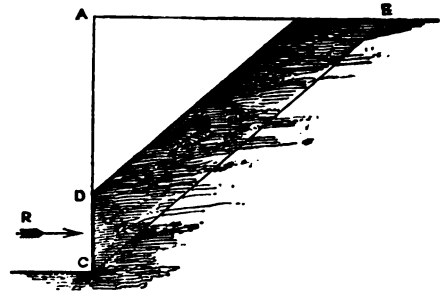


Fig. 4.

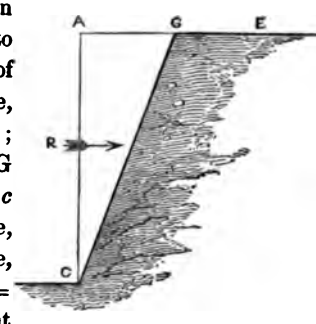


Fig. 5.

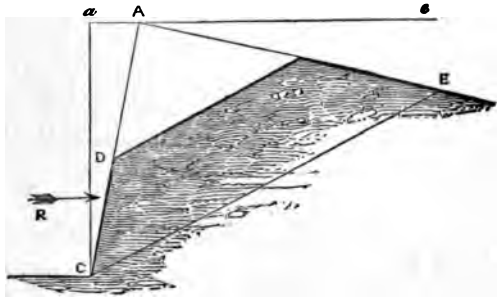


Fig. 6.

as for Figs. 4 and 5, the horizontal resistance being always expressed by

$$R = CGF, \text{ or } CDBF \times \tan. ECF.$$

It may be perceived that equations (5) and (7) are general for Figure 5, whether AE slopes from or to the face, C,G. The following investigation, however, furnishes a very simple construction for finding CF, and gives some other new forms for the values of R under different circumstances.

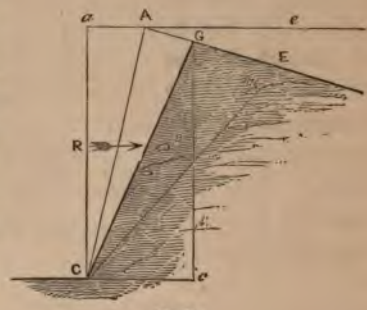


Fig. 7.

To determine the horizontal resistance, R, necessary to support the wedge, F,C,D, Fig. 8, and the position of CF, and the value of R, when it is a maximum.

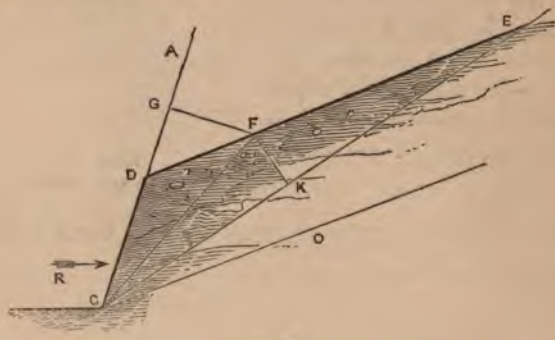


Fig. 8.

Put the angle, D,C,E, between the face, DC, and the plane of repose CE, $= c$; the angle, A,D,E, $= \theta$; the angle, D,C,F, $= \varphi$; the face, CD, $= h$; the perpendicular, FG, on CD, or CD produced $= y$, and DG $= x$.

By trigonometry tan. $\theta x = y$, and tan. F,C,E, $=$ tan. $(c - \varphi)$ $= \dfrac{\tan. c - \tan. \varphi}{1 + \tan. c. \tan. \varphi}$ and from the nature of the inclined plane, and putting W for the gravity of the stuff in F,D,C,

$$R = \frac{W\,h\,y}{2} \times \tan.\,(c - \varphi) = \frac{W\,h\,y}{2} \times \frac{\tan.\,c - \tan.\,\varphi}{1 + \tan.\,c \tan \varphi} \quad (20)$$

but $\tan.\,\varphi = \frac{y}{x+h} = \frac{\tan.\,\theta\,y}{y + \tan.\,\theta\,h}$; by substituting this value of $\tan.\,\varphi$ in (20) and reduction,

$$R = \frac{W\,h}{2} \times \frac{\tan.\,c\,(y^2 + h\,y \tan.\,\theta) - y^2 \tan.\,\theta}{y \tan.\,c \tan.\,\theta + y + h \tan.\,\theta} \quad (21)$$

When R is a maximum,

$$d\left(\frac{\tan.\,c\,(y^2 + h\,y \tan.\,\theta) - y^2 \tan.\,\theta}{y \tan.\,c \tan.\,\theta + y + h \tan.\,\theta}\right) = 0$$

By differentiating and solving the resulting quadratic there arises after a few easy reductions,

$$y = \left(\left(\frac{h \tan.\,\theta}{\tan.\,c \tan.\,\theta + 1} + \frac{h \tan.\,c \tan.\,\theta}{\tan.\,\theta - \tan.\,c}\right)\frac{h \tan.\,\theta}{\tan.\,c \tan \theta + 1}\right)^{\frac{1}{2}} - \frac{h \tan.\,\theta}{\tan.\,c \tan.\,\theta + 1} \quad (22)$$

and hence

$$x = \left(\left(\frac{h}{\tan.\,c \tan.\,\theta + 1} + \frac{h \tan.\,c}{\tan \theta - \tan.\,c}\right)\frac{h}{\tan.\,c \tan \theta + 1}\right)^{\frac{1}{2}} - \frac{h}{\tan.\,c \tan.\,\theta + 1} \quad (23)$$

If now CO is drawn parallel to DE, and δ is put $= \theta - c =$ the angle, ECO; $\tan.\,\delta = \tan.\,(\theta - c) = \frac{\tan.\,\theta - \tan.\,c}{1 + \tan.\,\theta \tan.\,c}$ hence $\tan.\,c \tan.\,\theta + 1 = \frac{\tan.\,\theta - \tan.\,c}{\tan.\,(\theta - c)} = \frac{\tan.\,\theta - \tan.\,c}{\tan.\,\delta}$: by substituting this value in (22) and (23) and making some reduction there results

$$y = \frac{h \tan.\,\theta}{\tan.\,\theta - \tan.\,c}\left(\sqrt{\tan.^2\delta + \tan.\,c \tan.\,\delta} - \tan.\,\delta\right) \quad (24)$$

$$x = \frac{h}{\tan.\,\theta - \tan.\,c}\left(\sqrt{\tan.^2\delta + \tan.\,c \tan.\,\delta} - \tan.\,\delta\right) \quad (25)$$

and hence

$$x + h = \frac{h}{\tan.\,\theta - \tan.\,c} \times \left(\sqrt{\tan.^2\delta + \tan.\,c \tan.\,\delta} + (\tan.\,\theta - \tan.\,c) - \tan \delta\right) \quad (26)$$

the values of the co-ordinates of the point F, also

$$\tan.\varphi=\frac{y}{x+h}=\frac{\sqrt{\tan.^2\delta+\tan.\,c\,\tan.\,\delta}-\tan.\,\delta}{\sqrt{\tan.^2\delta+\tan.\,c\,\tan.\,\delta+(\tan.\,\theta-\tan.\,c)\,\tan.\,\delta}}\quad(27)$$

but $\tan.\,(c-\varphi)=\dfrac{\tan.\,c-\tan.\,\varphi}{\tan.\,c\,\tan.\,\varphi+1}$; substituting in this equation the value of $\tan.\,\varphi$ in (27) and by reduction there results

$$\tan.\,(c-\varphi)=\tan.\,\mathrm{F,C,E,}=\sqrt{\tan.^2\delta+\tan.\,c\,\tan.\,\delta}-\tan.\,\delta\qquad(28)$$

Substituting both this value of $\tan.\,(c-\varphi)$ and that of y in (24) in (20) it becomes

$$\mathrm{R}=\frac{\mathrm{W}\,h^2}{2}\times\frac{\tan.\,\theta}{\tan.\,\theta-\tan.\,c}\left(\sqrt{\tan.^2\delta+\tan.\,c\,\tan.\,\delta}-\tan.\,\delta\right)^2\quad(29)$$

or as it may be expressed more neatly,

$$\mathrm{R}=\frac{\mathrm{W}\,h^2}{2}\times\frac{\tan.\,\theta}{\tan.\,\theta-\tan.c}\times\tan.^2(c-\varphi)=\frac{\tan.\,\theta-\tan.\,c}{2\,\tan.\,\theta}y^2\quad(30)$$

When $\theta=90°$, $\tan.\,\delta=\cot.\,c$, δ becomes equal to the complement of c, and (28,) after a few reductions, changes to

$$\tan.\,(c-\varphi)=\frac{\sec.\,c-1}{\tan.\,c}=\tan.\,\tfrac{1}{2}\,c$$

which shows that the equation of Prony holds good, whatever the inclination of the face, CD, may be, if DE be perpendicular to it; as in this case $\dfrac{\tan.\,\theta}{\tan.\,\theta-\tan.\,c}=1$ (30) becomes

$$\mathrm{R}=\frac{\mathrm{W}\,h^2}{2}\tan.^2\,\tfrac{1}{2}c$$

the same as (10.)

When $\theta=c$, $\delta=o$, therefore $c-\varphi$ (28) $=o$ and $c=\varphi$: in this case (20) $\mathrm{R}=\dfrac{h}{2}\tan.\,\mathrm{F,C,E,}\times y$, raise FK perpendicular to CF, hence $\tan.\,\mathrm{F,C,E}=\dfrac{\mathrm{F\,K}}{\mathrm{F\,C}}$ and $\mathrm{R}=\mathrm{W}\dfrac{\mathrm{DC}}{2}\times\dfrac{\mathrm{F\,K}}{\mathrm{F\,C}}\times\mathrm{G\,F}=\mathrm{W}\dfrac{\mathrm{DC}\times\mathrm{F\,K}}{2}\times\dfrac{\mathrm{G\,F}}{\mathrm{F\,C}}=\dfrac{\mathrm{W}\times\mathrm{DC}\times\mathrm{FK}}{2}\times\sin.\,\mathrm{FCG}$, but

when FC is infinite, FK is at right angles to DE, and = DC × sin. c, also in this case sin. F,C,G, = sin. c, therefore

$$R = \frac{D\,C^2}{2} \times \sin.^2 c = \frac{W\,h^2}{2} \times \sin.^2 c$$

which is the same as (18,) whatever the slope of D,C may be.

Equation (28) gives the following simple construction for finding the position of C,F. Through C, Figure 9, draw C,O parallel to D,E. Draw any line, A,K,O, at right angles to the line of repose, C, E, meeting C,D, or

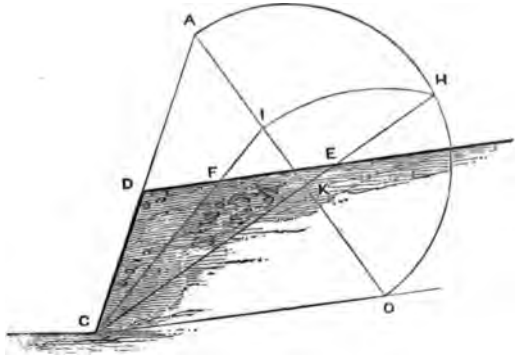


Fig. 9,

C,D the face produced in A, and C, O in O; on A,O describe a semicircle cutting C,E in H; from O, as centre, with O,H as distance, describe the arc, H,l, cutting A,O in I; join C,I, and produce it, if necessary, to meet D,E in F, then is CF the line required.* This construction is much more simple than that derived from equation (11.) In Fig. 10, the bank slopes downwards from C,D. in this case θ is obtuse, and its tangent is to be considered negative. When $\theta - c = \delta$ is acute, as

* This construction, with a few of the previous equations, have also been published in the Proceedings of the Royal Irish Academy, Vol. 3, Part 1, page 85.

in Fig. 10, the construction is the same as in Fig. 9; but

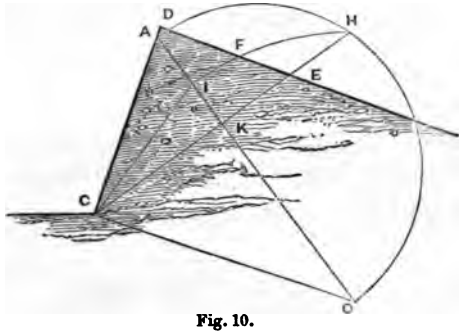


Fig. 10.

when $\theta - c$ is obtuse, tan. δ is negative, and tan. $(c - \varphi)$ $=$ tan. $\delta - \sqrt{\text{tan.}^2\theta - \text{tan. } c \text{ tan. } \delta}$ from which the following construction similar to the foregoing, may be derived, Fig. 11.

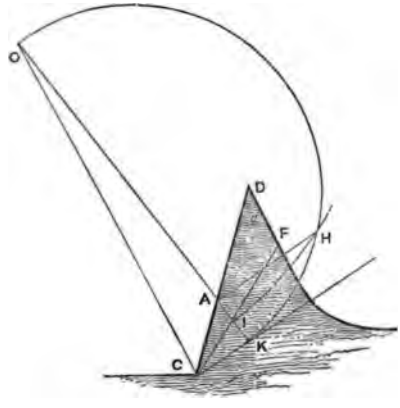


Fig. 11.

After proceeding as before, on OK describe a semicircle to cut a perpendicular at A in H, from O, as centre, with O,H, as distance, describe an arc to cut OK,

in I, join CI and produce it to F, then C,F is the line required.

The value of ECF $(c-\varphi)$ in (12) may be shown to be the same as in (28,): for b, in the former is equal to $90-\varphi$ in the latter; hence $\tan.b = \frac{1}{\tan.\theta}$; also $c+b$ in the latter, is equal to c in the former; hence, if in (12) we substitute $\frac{1}{\tan.\theta}$ for $\tan.b$, and $\tan.(c+b)$ for $\tan.c$, there results

$$\tan.(c-\varphi) = \frac{\sec.(c+b) - \sqrt{\tan.(c+b)\frac{1}{\tan.\theta}+1}}{\tan.(c+b)\sqrt{\tan.(c+b)\frac{1}{\tan.\theta}+1}}$$

by arranging this, and substituting for $\tan.(\theta-c) = \frac{\tan.\theta - \tan.c}{\tan.\theta\tan.c+1}$, the $\tan.\delta$, there will result, as before, the equation,

$$\tan.(c-\varphi) = \sqrt{\tan.^2\delta - \tan.c\tan.\delta} - \tan.\delta \qquad (28)$$

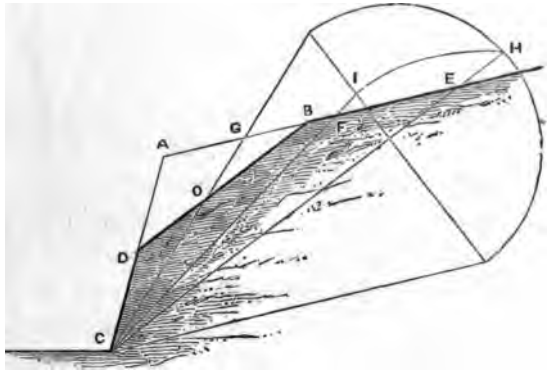


Fig. 12.

If CG be drawn so that the triangle, C,A,G, = the triangle, B,A,D, it is evident the equations (28) and (29) will also answer in the case of any bank, C,D,B,E. By putting CG = H the angle, ECG = c, and the other quantities, as before, as in (28)

tan. F,A,D = tan. $(c - \varphi) = \sqrt{\tan.^2\delta + \tan.\ c\ \tan.\ \delta} - \tan.\ \delta$ and by changing h into H (29) becomes

$$R = \frac{W\ h^2}{2} \times \frac{\tan.\ \theta}{\tan.\ \theta - \tan.\ c}\left(\sqrt{\tan.^2\delta + \tan.\ c\ \tan.\ \delta} - \tan.\ \delta\right)^2$$

and these equations are true whatever the form of the face, C,D,B, may be, provided the portion, D,O,C, cut off by C,G, is equal to the portion B,G,O, taken in, and the point, F, lies between B and E.

If the weight of the portion of the bank lying to the left of DF, be determined by computation in any of the preceding figures, and be multiplied by the natural tangent of the angle, F,C,E, the product will give the value of R, expressed in the same terms as the weight.

In sloping ground, the heights, H or h, should be taken from that point at the back of the wall, whose resistance is to be determined, on a level with the ground, C, G, in front (Figs. 1 and 2,) to where the vertical line would meet the top or slope. In fact, in order to determine the resistance, it is the height, C,H, in these figures, and not C,D, that should be made use of in the preceding equations. Indeed that portion of stuff lying between C, h, and the back of the wall is more effective in adding to its stability than diminishing it, and should never be taken into consideration in calculating the value of R; and hence, in the preceding equations and constructions for finding C,F, the case of the bank leaning forward was not considered separately, though the equations still apply to it, and are general. A bank can, however, never lean forward, unless retained by some force; but in the case of retaining walls, rising to the full height of the bank, the portion that lies in front of the vertical and on the wall, is a source of strength and not of weakness: as its own weight, at least, is

transmitted on the wall, and when loose and properly punned, it acts as a medium to distribute the pressure more equally over the resisting surface. These remarks, however, apply more to the subject of retaining walls than that of resistance merely, now under consideration.

TABLE 1. The values of R, under different circumstances, calculated from equation (10) when the bank is vertical, and the top horizontal; h being expressed in feet

$$R = \frac{W\,h^2}{2} \tan.^2 \tfrac{1}{2}\,c$$

For hydrostatic pressure $W = 62\frac{1}{2}$ lbs. and tan. $\frac{1}{2}c$ $=$ tan. $45° = 1$, hence $R = 31.25\,h^2$

1	2	3	4	5	6	7	8	9	10	11
Ratio of the slope corresponding to the angle of repose.	Angle of repose 90°—c.	Complement of the angle of repose.	tan. $\frac{1}{2}c$	tan.$^2\frac{1}{2}c$	The resistance—R in terms of W	The resistance—R in lbs. when W=92lbs. for some dry sand.	The resistance—R in lbs. when W=100lbs for other sand.	The resistance R in lbs. when W = 108lbs. as in dry clay.	The resistance R in lbs. when W = 112lbs. clay with water.	The resistance R in lbs. when W = 120lbs. for wet sand.
$3\frac{1}{2}$ to 1 nearly	16°	74°	.754	.569	$.284Wh^2$	$26.1h^2$	$28.4h^2$	$30.7h^2$	$31.8h^2$	$34.1h^2$
$3\frac{1}{3}$ to 1 nearly	17°	73°	.740	.548	$.274Wh^2$	$25.2h^2$	$27.4h^2$	$29.6h^2$	$30.7h^2$	$32.9h^2$
3 to 1 nearly	$18\frac{1}{2}$°	$71\frac{1}{2}$°	.720	.518	$.259Wh^2$	$23.8h^2$	$25.9h^2$	$28.\ h^2$	$29.\ h^2$	$31.1h^2$
$2\frac{1}{2}$ to 1 nearly	22°	68°	.675	.456	$.228Wh^2$	$21.\ h^2$	$22.8h^2$	$24.6h^2$	$25.5h^2$	$27.1h^2$
2 to 1 nearly	27°	63°	.613	.376	$.188Wh^2$	$16.7h^2$	$18.8h^2$	$20.5h^2$	$21.1h^2$	$22.6h^2$
	33°	57°	.543	.295	$.147Wh^2$	$13.5h^2$	$14.7h^2$	$15.9h^2$	$16.5h^2$	$17.6h^2$
$1\frac{1}{2}$ to 1 nearly	34°	56°	.532	.283	$.141Wh^2$	$13.\ h^2$	$14.1h^2$	$15.2h^2$	$15.8h^2$	$16.9h^2$
	35°	55°	.521	.271	$.135Wh^2$	$12.4h^2$	$13.5h^2$	$14.6h^2$	$15.1h^2$	$16.2h^2$
$1\frac{1}{3}$ to 1 nearly	$37\frac{1}{2}$°	$52\frac{1}{2}$°	.493	.243	$.121Wh^2$	$11.1h^2$	$12.1h$	$13.1h^2$	$13.6h^2$	$14.5h^2$
$1\frac{1}{4}$ to 1 nearly	39°	51°	.477	.228	$.114Wh^2$	$10.5h^2$	$11.4h^2$	$12.3h^2$	$12.8h^2$	$13.7h^2$
	42°	48°	.445	.198	$.99Wh^2$	$9.1h^2$	$9.9h^2$	$10.8h^2$	$11.1h^2$	$11.9h^2$
1 to 1	45°	45°	.414	.171	$.85Wh^2$	$7.8h^2$	$8.5h^2$	$9.2h^2$	$9.5h^2$	$10.2h^2$
$\frac{3}{4}$ to 1 nearly	53°	37°	.335	.112	$.56Wh^2$	$5.2h^2$	$5.6h^2$	$6.\ h^2$	$6.3h^2$	$6.7h^2$

The angles of repose of most materials in a loose and dry state, vary between 40° and 34° or the materials stand on slopes, between one and a quarter to one, and one and a half to one, nearly. If, however, the stuff or plane of fracture, C,F, becomes saturated with water, the friction on the plane is reduced thereby, and the angle of repose becomes flatter; on the contrary, if the friction be increased, as it may be, by projecting masses, as stones, &c. in C,F, the angle of repose becomes steeper, hence the reason of calculating the above table for different angles of repose between 16° and 53°: the former requiring, with stuff of 112 lbs. per cubical foot, a resistance of 31.8 h^2 being a little more than hydrostatic pressure of 31.25 h^2; and the latter only requiring a resistance in the same case of 6.3 h^2 being only one fifth of the former. It appears, therefore, that through the agency of water in reducing the friction, the resistance required may be increased in column 10 from 15.8 h^2 at an angle of repose of 34°, up to 31.8 h^2 at an angle of repose of 16°, as stuff sometimes, when saturated, takes a slope of about $3\frac{1}{2}$ to 1, that is, the resistance required in the latter case is double that required in the former, and hence the necessity of cutting or draining off water from the back of banks, slopes, and retaining walls. But if the friction on C,F did not at first exceed $\frac{1}{\text{cot. } 53°}$ and consequently in column 10, the resistance not exceeding 6.3 h^2, and afterwards the friction became $\frac{1}{\text{cot. } 16°}$ the resistance would become 31.8 h^2 or five times the former; and hence the inevitable destruction of any revetment wall or bank calculated only to give the former resistance.*

* "Springs which have an impeded issue to the surface, are the most general cause of land-slips: we may consider the great fall of the Rossberg as a case of this kind, the water entering and moistening a particular layer of strata, all inclined very highly, so as easily to acquire a descending force, if the cohesion of the parts were weakened by interposed moisture." Phillips's Geology, Vol. 1, p. 326. Water lubricates the fissures, decreases the friction, and increases the value of R. Retaining walls have sometimes been bodily moved forward where founded on clay of little friction, or flat angles of repose: in such cases R, the resistance, must be greater than f, the friction on the base.

If in addition to the reduction of friction by the saturation of the stuff, or the percolation of water through the vein or fracture, C,F, it be supposed that the water has no means of escape at C, or elsewhere, there must then be added to the value of R, determined from the preceding principles, the hydrostatic pressure. If $s, s', s,''$ &c. be the projections of the different portions exposed to the pressure of the surface F, C on a front vertical plane, and $h, 'h, ''h''$ their mean hydrostatic heights, then this pressure will be $62.5 \times (sh' + s'h'' + s''h''')$ &c. If the whole of FC be exposed to the pressure, then this expression becomes equal to $31\frac{1}{4}\ h^2$ and hence the value of R in the preceding equations, or table, must be increased by $31.25\ h^2$ which would give in the first line of column 10, a resistance of $31.8\ h^2 + 31.25\ h^2 = \ .33\ h^2$ or something more than double hydrostatic resistance. The effect of W, however, becomes lessened by the pressure upward, which is easily calculated. This is quadruple the mean maximum resistance $15.8\ h^2$ at an angle of repose of 34°, and ten times the resistance $6.3\ h^2$ at an angle of repose of 53° These changes in the value of R are sufficient to account for the slips that take place in cuttings, even when the sides are cut to a very flat slope; and that they do not take place in embankments with the same slopes, when standing on a firm ground, is a proof that water, by reducing the friction, acting by its pressure, or by both united, is the cause, in connexion with the geological arrangement of the strata or veins, of these slips.

It has been shown that the equation $R = \frac{W h^2}{2} \tan^2 \frac{1}{2} c$ is true for a bank, C,D sloping from the vertical with the top, D,E, at right angles to it; if the angle D,C,E, between the line of repose, C,E and the face, C,D be called c and C,D, h; as well as when CD is vertical, and DE horizontal. The angle, c, here is there-

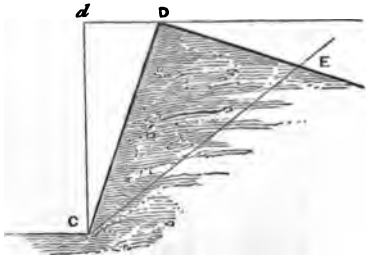


Fig. 13.

fore equal to the complement of the angle of repose, less the angle D,C,d, and the height, h, is the slant height, C,D.

TABLE 2.—The values of R, under different circumstances, in Fig. 13, when C D declines 10° from the vertical. The angle of repose varying from 27° or 2 to to 1, to 45° or 1 to 1.

$$R = \frac{W\,h^2}{2} \tan.\ {}^2\tfrac{1}{2}\ c$$

1	2	3	4	5	6	7	8	9	10	11
Slope corresponding to the angle of repose.	Angle of repose.	Complement of the angle of repose, less 10° = c.	tan. ½ c	tan. 2½ c	The resistance R in terms of W.	Value of R in lbs. when W=92lbs.	Value of R in lbs. when W=100lbs.	Value of R in lbs. when W=108lbs.	Value of R in lbs. when W=112.	Value of R in lbs. when W=120.
2 to 1 nearly	27°	53°	.499	.249	.124 W h^2	11.4h^2	12.4h^2	13.4h^2	13.9h^2	14.9h^2
	29°	51°	.477	.228	.114 W h^2	10.5h^2	11.4h^2	12.3h^2	12.8h^2	13.7h^2
	31°	49°	.456	.208	.104 W h^2	9.6h^2	10.4h^2	11.2h^2	11.6h^2	12.5h^2
	33°	47°	.435	.189	.94 W h^2	8.6h^2	9.4h^2	10.2h^2	10.6h^2	11.3h^2
1½ to 1 nearly	35°	45°	.414	.171	.85 W h^2	7.8h^2	8.5h^2	9.2h^2	9.6h^2	10.2h^2
1⅓ to 1 nearly	37°	43°	.393	.154	.77 W h^2	7.1h^2	7.7h^2	8.3h^2	8.6h^2	9.2h^2
1¼ to 1 nearly	39°	41°	.374	.140	.70 W h^2	6.4h^2	7. h^2	7.6h^2	7.8h^2	8.4h^2
	41°	39°	.354	.125	.63 W h^2	5.8h^2	6.3h^2	6.8h^2	7.1h^2	7.6h^2
	43°	37°	.335	.112	.56 W h^2	5.2h^2	5.6h^2	6.1h^2	6.3h^2	6.7h^2
1 to 1	45°	35°	.315	.99	.50 W h^2	4.2h^2	5. h^2	5.4h^2	5.6h^2	6. h^2

These values are found to the slant height, CD $= h$ and as $CD^2 = \sec.^2 D,C, d \times C\, d^2 = \sec.^2 10° \times C\, d^2 = \overline{1.0154}|^2 \times Cd^2 = 1.031 \times C\, d^2$ they must be multiplied by 1.031 if the vertical height, c,d, be used in place of the slant height in the equation. If, therefore, each of the above values of R be multiplied by 1.031, and then compared with the corresponding values of R, in Table 1, it will be seen that the value of R when CD is vertical, and DE horizontal, exceeds the value of R when these lines incline 10 degrees, as in Fig. 13, by nearly one-half, that is one and a half times the latter value of R is nearly equal to the former value.

Hence, when the lines, CD, and DE, each incline 10 degrees, the value of R is reduced by one-third, nearly, from what it would be when these lines are vertical. The true reduction in the value of R, in each case to the same vertical height, being found by multiplying R, in Table 2, by 1.031, and subtracting the product from the corresponding value of R in Table 1.

TABLE 3.—The values of R, in Fig. 5, under different circumstances, when the face, C,G, declines 10 degrees from the vertical, and the top, G,E, is horizontal. From Equation (7)

$$R = \frac{h^2\, W}{2}\left(\frac{\sec.\, c - \sqrt{\tan.\, b}\, \tan.\, c + 1}{\tan.\, c}\right)^2$$

$$\tan.\, b = \tan.\, 10° = .176$$

1	2	3	4	5	5. *a*	5. *b*	6	7	8	9	10	11
Angles of repose.	c	sec. c	tan. c	$\frac{\sec. c - \sqrt{\tan. b \tan. c + 1}}{\tan. c}$	Results of col. 5.	Squares of Nos. in col. 5 *a*.	Resistance (R) in terms of W.	R when W = 92lbs.	R when W = 100lbs.	R when W = 108lbs.	R when W = 112lbs.	R when W = 120lbs.
27°	63°	2.203	1.963	$\frac{2.203 - \sqrt{1.3454}}{1.963}$	.531	.2820	.141 W h^2	13. h^2	14.1h^2	15.2h^2	15.8h^2	16.9h^2
29°	61°						.129 W h^2	11.9h^2	12.9h^2	13.9h^2	14.4h^2	15.5h^2
31°	59°	1.942	1.664	$\frac{1.942 - \sqrt{1.2928}}{1.664}$	.484	.2343	.117 W h^2	10.8h^2	11.7h^2	12.6h^2	13.1h^2	14. h^2
32°	58°						.111 W h^2	10.2h^2	11.1h^2	12. h^2	12.4h^2	13. h^2
33°	57°	1.836	1.540	$\frac{1.836 - \sqrt{1.2710}}{1.540}$	.460	.2116	.106 W h^2	9.8h^2	10.6h^2	11.4h^2	11.9h^2	12.7h^2
34°	56°						.101 W h^2	9.3h^2	10.1h^2	10.9h^2	11.3h^2	12. h^2
35°	55°	1.743	1.428	$\frac{1.743 - \sqrt{1.2513}}{1.428}$	.437	.1910	.095 W h^2	8.7h^2	9.5h^2	10.3h^2	10.6h^2	11.4h^2
36°	54°						.090 W h^2	8.3h^2	9. h^2	9.7h^2	10.1h^2	10.8h^2
37°	53°	1.662	1.327	$\frac{1.662 - \sqrt{1.2366}}{1.327}$	.411	.1689	.084 W h^2	7.7h^2	8.4h^2	9.1h^2	9.4h^2	10.1h^2
39°	51°						.077 W h^2	7.1h^2	7.7h^2	8.3h^2	8.6h^2	9.2h^2
41°	49°	1.524	1.150	$\frac{1.524 - \sqrt{1.2024}}{1.150}$	.371	.1376	.069 W h^2	6.4h^2	6.9h^2	7.5h^2	7.7h^2	8.3h^2
43°	47°						.062 W h^2	5.7h^2	6.2h^2	6.7h^2	6.9h^2	7.4h^2
45°	45°	1.414	1.000	$\frac{1.414 - \sqrt{1.1760}}{1}$	.330	.1089	.054 W h^2	5. h^2	5.4h^2	5.8h^2	6. h^2	6.5h^2
47°	43°						.048 W h^2	4.4h^2	4.8h^2	5.2h^2	5.4h^2	5.8h^2
49°	41°	1.325	.869	$\frac{1.325 - \sqrt{1.1529}}{.869}$	.289	.0835	.042 W h^2	3.9h^2	4.2h^2	4.5h^2	4.7h^2	5. h^2
51°	39°						.036 W h^2	3.3h^2	3.6h^2	3.9h^2	4.0h^2	4.3h^2
53°	37°	1.252	.754	$\frac{1.252 - \sqrt{1.1327}}{.754}$	.249	.0615	.031 W h^2	2.9h^2	3.1h^2	3.3h^2	3.5h^2	3.7h^2
55°	35°						.027 W h^2	2.5h^2	2.7h^2	2.9h^2	3. h^2	3.2h^2
57°	33°	1.192	.649	$\frac{1.192 - \sqrt{1.1142}}{.649}$	.211	.0445	.022 W h^2	2. h^2	2.2h^2	2.4h^2	2.5h^2	2.6h^2

Though the value of R is almost invariably to be sought for in the lines for the angles of repose, between 34° and 45° in this table, the table has yet been extended farther, in order that it may be rendered applicable to Fig 7, when the angle, A,C,G $= b$ is also ten degrees. It has already been shown that equation (7) applies equally to this figure as to Fig. 5, but that the angle, A,C,E, $= c$ in Fig. 7, is equal to the complement of the angle of repose in Fig. 5. Hence c, in Fig. 7, is equal to the complement of the angle of repose, less the inclination of AC from the vertical, or, which is the same thing, less the inclination of A,E from the horizontal. Hence, for Fig. 7, $c =$ complement of the angle of repose, less the angle, ACa, (or E a e.) Suppose the angle of repose to be 33° the complement will be 57°; if the ground falls at an inclination of 20°, then for Fig. 7,

$$c = 57° - 20° = 37°$$

and opposite this value, taken in column 2, will be found the value of the resistance

$$R = .031\ W\ h^2$$

If the fall of the ground is 24° then $c = 57° - 24° = 33°$ and opposite this angle, taken in column 2, will be found $R = .022\ W\ h^2$ The table does not extend farther than this or for $c = 33°$

The table has been calculated for differences of 4° in the angles, and unless near the angles of repose where the calculations were made for every two degrees, the intermediate values were found by easy interpolation. The value of R can be found for any degree or half degree in the angle, c, within the limits of the table, by interpolation from the angles given, for the next adjacent angles. The values of R are given to degrees about the usual angles of repose.

The height, h, in the table, is the height, C,A, found (Figs. 5 and 7,) by letting fall a perpendicular, CA, from the bottom of the face, CG, on the line, EG, or the top of the bank produced; and not the slant height, C,G, nor vertical height of G above C G c. Fig. 7, found by letting fall a perpendicular, G c from G, on a horizontal line through C: — As $\frac{CG^2}{\text{sec.}^2 b} = C,A^2 = h^2$ and CG $= G\,c \times \text{sec. } CG\,c$, $CA^2 = h^2 = \frac{G\,c^2 \times \text{sec.}^2 CGc.}{\text{sec.}^2 b}$ If i be the inclination of AC, from the vertical $=$ the angle AC a, then $h^2 =$

$\frac{CG^2}{\sec.^2 b} = CG^2 \times \cos.^2 b$, which value, when substituted in Equation 7, or Table 3 for h^2 will give the value of R in terms of the slant height, CG, and as also $h^2 = G\,c^2 \times \frac{\sec.^2 CGc^2}{\sec.^2 b} = \frac{G\,c^2 \times \sec.^2(i+b)}{\sec.^2 b} = \frac{G\,c^2 \times \cos.^2 b}{\cos.^2(i+b}$ which value, substituted in like manner for h^2 will give the value of R in terms of the vertical height, G c, of G above c. Hence the Equation 7 may be changed into (Fig. 7.)

$$R = \frac{CG^2 \times W}{2}\left(\frac{1}{\sec.\,b} \times \frac{\sec.\,c - \sqrt{\tan.\,b \tan c + 1}}{\tan.\,c}\right)^2 \quad (31)$$

which gives the value of R in terms of the slant height, C,G, also

$$R = \frac{Gc^2\,W}{2}\left(\frac{\sec.\,(i+b)}{\sec.\,b} \times \frac{\sec.\,c - \sqrt{\tan.\,b \tan.\,c + 1}}{\tan.\,c}\right)^2 \quad (32)$$

which gives the value of R in terms of the vertical height, Gc, of G above C: $(i+b)$ being equal to the angle CGe = the angle, GCa. Equation (7) is, however, simpler than either of the two last, and it is therefore more convenient for calculation to use the height, or perpendicular, CA = h, as in this Equation, and Table 3, than either the slant height, CG, in (31,) or the vertical height, Gc, in (32.)

From Equation 8, involving the heights, H and h, otherwise than as co-efficients to the whole function of θ and c, it has been considered unnecessary to give a table for the values of R under different circumstances, so many relations may exist between H and h. The equation, however, is simple, and the calculation can be easily made, for any particular case from it directly; or by means of the construction already pointed out, Equation 7 may be used in place of it.

Equation (29,) as has already been shown, is general in its application, and is easily applied to such cases as Fig. 13. In order to compare the results of calculations made from it, with those already tabulated, (Table 3,) two examples are given:—

$$R = \frac{W\ h^2}{2} \times \frac{\tan.\ \theta}{\tan.\ \theta - \tan.\ c}\left(\sqrt{\tan.^2\ \delta + \tan.\ c\ \tan.\ \delta} - \tan\ \delta\right)^2 \quad (29)$$

Example 1—Let $\theta = 80°$ and $c = 47°$ then $\delta = \theta - c = 80° - 47° = 33°$ hence $R = \frac{W h^2}{2} \times \frac{5.671}{5.671 - 1.072}\left(\sqrt{(.649 + 1.072) \times .649} - .649\right)^2$

but $\frac{5.671}{5.671 - 1.072}(\sqrt{1.721 \times .649} - .649)^2 = \frac{5.671}{4.599}(\sqrt{1.117} - .649)^2$

$= \frac{5.671}{4.599}(1.057 - .649)^2 = \frac{5.671}{4.599}(.408)^2 = \frac{5.671}{4.599} \times .167 = .205$

hence $R = \frac{W\ h^2}{2} \times .205 = W\ h^2 \times .103 = .103\ W\ h^2$. Now in Table 3, fifth line, $c = 57°$ and $b = 10°$ hence θ is equal to $90° - 10° = 80°$ (Fig. 5,) and $c - b = 47°$; also $R = .106\ W\ h^2$ If this value be divided by $\sec.^2\ 10° = (1.0154)^2$, as $\frac{h^2}{\sec.^2\ b}$ in (7) is equal h^2 in (29), there results $R = .103\ W\ h^2$ the same as found in the example.

Example 2.—Let $c = 45°$ and $\theta = 80°$ then $\delta = \theta - c = 35°$ hence $R = \frac{W\ h^2}{2} \times \frac{5.671}{5.671 - 1}\left(\sqrt{(.700 + 1) \times .700} - .700\right)^2$

but $\frac{5.671}{4.671}(\sqrt{.119} - .7)^2 = \frac{5.671}{4.671}(.39)^2 = \frac{5.671}{4.671} \times .1521 = .185$,

hence $R = \frac{W\ h^2}{2} \times .185 = .0925\ W\ h^2$ If this be multiplied by $\sec.^2\ b = 10°$ then $R = .095\ W\ h^2$ to the height, A,C, Fig. 5, the same as given in the seventh line of Table 4.

In the Article, Masonry, in the Encyclopedia Brittanica, 7th Edition, by Tredgold, there is given the following equation, for calculating the pressure of earth and fluids, against walls, when the resistance is a maximum.

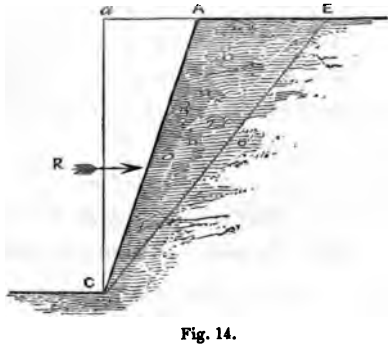


Fig. 14.

$$(23) \quad \tan.\ a = \frac{-1+(\tan.\ c\ \tan.^3 i+\tan.^2 i+\tan.\ c\ \tan.\ i+1)^{\frac{1}{2}}}{\tan.\ i}$$

Which, by factoring, can be reduced to the same form as Equation 5 in this paper, and

$$(25)\ R=\frac{h^2\,S}{2\tan i}\left\{\tan.i+\tan.c+\frac{2}{\tan.i}-2\left(\tan.\ c\ \tan.\ i+\frac{\tan.\ c+1}{\tan.\ i}+1\right)^{\frac{1}{2}}\right\}$$

Where $a =$ the angle, EC a, which the plane of fracture, E,C, makes with the vertical line, C a; $i =$ the complement of the angle of repose; $h =$ AC, the vertical height; and S $=$ the weight of a cubical foot of the material in the wedge, C,A,E. It is asserted that when the face, CA, is vertical, (25) here given becomes

$$(26) \qquad R=\frac{h^2\,S}{2}\tan.^{2\frac{1}{2}}\ i$$

Now though this (26) is correct, it cannot be derived from (25) which is incorrect, as well as complex, though derived from the particular case where C a is vertical, and consequently A,E horizontal. The table calculated from (25) and (26) given in the Encyclopedia, is as follows:—

Tredgold's Table for the value of R.

Table of constant quantities necessary for calculating the pressure of some materials.

		Angle of repose.	Weight of a cubic foot.	Value of R in Equation (26)	Value of R in Eq. (25) $c = 10°$
1	Water	0	62.5 lbs.	$R = 31\frac{1}{4}\,h^2$	$R = 31\frac{1}{4}\,h^2$
2	Fine dry sand ..	33°	92 —	$R = 13.8\,h^2$	$R = 4.8\,h^2$
3	Do. moist...	——	119 —	$R = 17.85h^2$	$R = 6.2\,h^2$
4	Quartz sand (dry)	35°	102 —	$R = 13.77h^2$	$R = 4.6\,h^2$

Table 4, constructed from Tables 1 & 3, for the value of R, to the same constant quantities as in Tredgold's Table.

		Angle of repose.	Weight of a cubic foot W =	Value of R from Table 1, or Eq. (10)	Value of R from Table 3 or Eq. (7) $b = 10°$
1	Water	0	62.5 lbs.	$\frac{Wh^2}{2} = 31\frac{1}{4}\,h_2$	$\frac{Wh^2}{2} = 31\frac{1}{4}\,h^2$
2	Fine dry sand ..	33°	92 —	$.147\,Wh^2 = 9.7\,h^2$	$.109\,Wh^2 = 9.7\,h^2$
3	Do. moist...	——	119 —	—— $17.5\,h^2$	—— $12.6\,h^2$
4	Quartz sand (dry)	35°	102 —	$.135\,Wh^2 = 13.8\,h^2$	$.095\,Wh^2 = 9.7\,h^2$

The values of R, when the face is vertical, in this table, agree with those of Tredgold, there being only a slight difference in the decimal place of the co-efficient to h^2 but the values when the face declines 10° are double those given by Tredgold. Those in Table 4, are, however, correct, as has been proved in the two examples worked from Equation 29, page 131, and which were worked out, merely for the purpose of testing, by a calculation different from that in Table 3, the values there given for R, and transferred to the above Table 4.

It is easy to show equation (26) given by Tredgold, as derived from equation (25,) cannot be derived from it, for when c in (25) is $= 0$, $R = \frac{h^2\,S}{2\tan.\,i}\left(\tan.\,i + \frac{2}{\tan.\,i} - 2\left(\frac{1}{\tan.\,i} + 1\right)^{\frac{1}{2}}\right)$ $= \frac{h^2 S}{2}\left(\frac{\tan.^2 i + 2 - 2\,(\tan.^2 i + \tan.\,i)^{\frac{1}{2}}}{\tan.^2 i}\right)$ Now as $\tan.^2 \frac{1}{2}\,i = \frac{(\sec.\,i - 1)^2}{\tan.^2 i}$ it is evident if this value of R is true, that $(\sec.\,i - 1)^2$ must be equal $\tan.^2 i + 2 - 2\,(\tan.^2 i + \tan.\,i)$ or $\tan.^2 i + 1 - 2\sqrt{\tan.^2 i + 1} + 1 = \tan.^2 i + 2 - 2\,(\tan.^2 i + \tan.\,i)$ or $-2\sqrt{\tan.^2 i + 1} = -2\sqrt{\tan.^2 i + \tan.\,i}$, hence $\tan.\,i$ should be equal unity which can only occur when $i = 45°$. But to determine where the error lies—

Equation (7) in this paper gives $R = \frac{H^2 W}{2}\left(\frac{\sec.\,c\sqrt{\tan.\,b\tan c + 1}}{\tan.\,c}\right)^2$

This may be changed as follows: $\left(\frac{\sqrt{\tan.^2 + 1} - \sqrt{\tan.\,b\tan c + 1}}{\tan.\,c}\right)^2$

$$=\left(\frac{\sqrt{\tan.\,c+\frac{1}{\tan.\,c}}-\sqrt{\tan.\,b+\frac{1}{\tan.\,c}}}{\sqrt{\tan.\,c}}\right)^2$$

$$=\frac{1}{\tan.\,c}\left(\sqrt{\tan.\,c+\frac{1}{\tan.\,c}}-\sqrt{\tan.\,b+\frac{1}{\tan.\,c}}\right)^2$$

$$\frac{1}{\tan.c}\times\left(\tan.c+\frac{1}{\tan.c}+\tan.b+\frac{1}{\tan.c}-2\sqrt{\tan.c\tan.b+1+\frac{\tan.b}{\tan.c}+\frac{1}{\tan.^2c}}\right)$$

$$=\frac{1}{\tan.\,c}\left(\tan.\,c+\tan.\,b+\frac{2}{\tan\,c}-2\sqrt{\tan.c\tan.b+1+\frac{\tan.\,b\,\tan.\,c+1}{\tan.\,^2c}}\right)$$

hence equation (7)becomes

$$R\left\{\begin{array}{l}=\frac{H^2W}{2}\times\frac{\left(\sqrt{\tan.\,c+\frac{1}{\tan.\,c}}-\sqrt{\tan.\,b+\frac{1}{\tan.\,c}}\right)^2}{\tan.\,c}=\\ =\frac{H^2W}{2}\times\frac{(\sqrt{\tan.\,c+\cot.\,c}-\sqrt{\tan.\,b+\cot.\,c})^2}{\tan.\,c}\end{array}\right\}(33).$$

and also by squaring the second member, as above, this becomes

$$R=\frac{H^2W}{2\tan.\,c}$$

$$\times\left(\tan.\,c+\tan.b+\frac{2}{\tan.\,c}-2\sqrt{\tan.c\tan.b+1+\frac{\tan.c\tan.b+1}{\tan.\,^2c}}\right)(34)$$

Comparing this with Tredgold's equation, (25,) it will be seen that the error lies in the term, $\frac{\tan.\,c+1}{\tan.\,c}$ under the vinculum, which should be $\frac{\tan.\,c\ \tan.\,i+1}{\tan.^2\,i}$, and this being the case, the very complex form is easily reduced to equation (7) or to equation (33) given above, which is simple and easy to calculate from, as the terms under the vinculum are easily taken out, and can be added mentally, without writing down each term separately.

In the remarks following Table 1, there were pointed out the many changes which the values of R may undergo, according to varying circumstances. To control these circumstances, so as the least value of R, or what may be called the *minimum maximorum* value only, may be required, and provided for, is the province of the Engi-

neer. But the particular case being determined, or its greatest probable limit, the determination of R becomes then a question of calculation, the means of performing which, for the different forms of banks and ground mentioned, has been the object of this paper, as well as also to point out the varying nature of the constants, and to show, that theory, properly interpreted, meets and explains the almost constant variety that occurs in practice. The form of fracture is, however, in practice, seldom found to be a straight line, but hollow or concave to the face. This arises from want of homogeneity in the materials, or their arrangement; or from the force, by which the fracture was produced, acting differently, at different points; and also from the parts next the surface at top, being tougher, and more closely connected with roots of grasses, &c. than near the bottom, and having a steeper angle of repose. It is almost impossible to reduce such cases to strict calculation without begging the question, and supposing some law of change in the density of the stuff and angle of repose, which would probably hold good in no two cases. The mean case is that which ought to be calculated from, namely, that which—considering the particular circumstances—gives a mean angle of repose and density, to the whole bank. The preceding Equations, then, determine the value of R, and the position of the fracture, when R is a maximum.

A horizontal section is also most frequently, if not always, concave to the face. This arises from unequal pressure from behind, and want of homogeneity also; but the pressure in such cases can, evidently, never exceed the maximum resistance determined in the preceding equations, when the constants are taken for the extreme case at the middle of the slip.

The value of R is the most important element involved in the equations for determining the dimensions for retaining walls. The Table of dimensions given by Tredgold in the article already mentioned, in the Encyclopedia Brittanica, must appear, to a practical person, as worse than useless, and it has been shown that the dimensions for leaning walls have been calculated for an amount of resistance only half of what it should be. But the other elements adopted in the calculation of that table are questionable as to amount, and also as to the application of cèrtain principles to the particular subject under consideration.

The amount of the resistance required is often increased by addition of weight or momentum to the wedge of fracture, which may occur on quays, and where stuff is put to spoil along the edge of cuttings, &c. These additions of weight may often cause a fracture to take place where none previously existed, and unless walls are calculated to give the maximum amount of resistance required, they may stand for years, and then fail. The failure may not take place immediately after a fracture in the bank takes place, but after it is penetrated by water, when the angle of repose is reduced, and perhaps also hydrostatic pressure brought into play. Hence the necessity of taking the maximum values of R; and the prudence of the engineering maxim, "stronger than strong enough," will lead us to taking the element from which it is determined the largest that will probably arise in the particular case under consideration.

The angle of repose, even in the same bank, is not the same at different times. When stuff is tipped into embankment, the angle of repose is least, and when adhesion and consolidation take place, it is greatest. The more

perfect drainage there is from embankments, tends also to increase the angle of repose, and reduce the resistance. Though soil weighs up to one-eighth more in embankment than it does before being cut *in situ*, yet this increase in the value of W is more than counteracted, in the value of R, by the increase, from more perfect drainage, in the angle of repose. Dry sand, when tipped over, takes a slope of about one and-a-half to one; yet after standing for a short time, if undermined, it will slip to a slope of only five or six inches to a foot, or about one-half to one. Banks, in cuttings, and fillings after consolidation, will stand with a vertical face for many feet in depth, if well drained, and no force be applied on top, and will remain so, until the weather scales off the faces to slopes, on which vegetation can take place. Dry loose sand, and other dry soils, will contract their volume when wet, and when saturated the angle of repose will decrease. Where soil contracts when wet, the value of W will greatly increase, as it is affected both by the increased density of the soil, and by the quantity of water filling its interstices. A knowledge of these facts will give hints as to the best manner of building retaining walls, and of bringing up the earthwork behind, which are most valuable. These—the best mode of procedure, with the dimensions of various forms of walls, under different circumstances, sufficient to afford a resistance equivalent to R—may form the subject of some future paper.

"*Results of Experiments on Retaining Walls,* communicated by JACOB OWEN, ESQ. C.E. M.R.I.A. Member.

THE absence of sound knowledge, founded on experimental investigation, has ever been a serious disadvantage in the consideration of the section which it may be deemed advisable to give to retaining walls, under different circumstances; and after the reputation of the young Engineer is placed in danger, by the failure, from insufficiency, of a wall, the section of which he may have accurately ascertained by theoretical calculations, but which, when practically applied, proved too plainly, that although theory may be, and undoubtedly is, of great utility, when combined with, and attended by practice, yet when adopted as the sole guide, it will frequently lead into a labyrinth of errors. A transition to the opposite extreme, or the adaptation of a very strong wall, to counteract a comparatively light resistance, is an error, although not equally observable by the non-professional eye, still alike disreputable to the character of the designer, as involving an unnecessary cost in the construction.

Though it is true, that the failure of a wall does not always, of necessity, prove the insufficiency of the cross section, as there are other causes, which, if not guarded against, will produce the same effect, (such as badly executed workmanship, inferior materials, weak foundation, want of provision for the discharge of the collected moisture behind, &c. &c.) yet this view of the case is too often overlooked, and in attempting to rectify the error, the chance of a second failure is sought to be guarded against by pecuniary sacrifice, and the sectional area, in the former instance sufficient, if judiciously applied, is

unnecessarily increased, and perhaps with the same unfortunate results.

It is almost impossible, in reviewing the circumstances of many retaining walls which have failed, to arrive at general conclusions, which might form sufficient data in all cases, in consequence of the difficulty of finding two examples, in which the same conditions have been fulfilled: hence it may happen, that though the form and mode of construction of a wall, which has withstood the opposing force to which it had been subjected, without exhibiting the slightest symptom of failure, may be followed in a servile manner by the Engineer, in preparing a design for a wall for a similar purpose, but in a different locality, yet a downfall may take place before the work has even been carried to its full height.

Impressed with these views, the Commissioners of Public Works in Ireland conceived that much advantage would result from instituting some experiments, even on a limited scale, but which should be conducted as nearly as possible, under similar circumstances, or that the nature of the material, the workmanship, the foundations, the resistance to be overcome, the filling to be used, the state of the weather during the operations, &c. should be similar in each of the walls subjected to experiment. In the latter end of the year 1834, they directed that the experimental walls (plans and sections of which are given, Plate 6) should be built at Kingstown, on a site judiciously selected for the purpose. As it was deemed most advisable, that some of the walls should fail, it was determined that the sectional area should be the least, which, under the most favourable adaptation, could sustain the pressure to which it was to be subjected; and for this purpose, the mean thickness was fixed at one sixth of the height, the height

being 20 feet, and the mean thickness 3 feet 4 inches. Four separate retaining walls of the same length and height, and of equal sectional area, but of different form, were built nearly in juxta position, and in order that the filling behind should press upon each wall, separately, and equally, divisional walls, 2 feet 6 inches thick, were built between each, as shown by the plan. The several walls were founded upon solid rock, and built of ordinary rubble masonry, weighing 142 lbs. per cubic foot, the filling behind, being loose mould, which freely imbibed the rain and the moisture, and the weight of which when filled in, was equal to 87 lbs. per cubic foot.

The wall marked A, on plan, was built of a parallel thickness, and sloping 4 feet in the entire height, or $2\frac{2}{3}$ inches per foot. The wall B was built with a batter on the face of 4 feet in the entire height, or $2\frac{2}{3}$ inches per foot, the back being perpendicular. The wall C was constructed plumb on the face, and with the same batter on the back, as on the face of the wall B, and the fourth wall D, was built plumb, and of a parallel thickness. As these walls were executed simultaneously, and consequently subject to the same changes of the weather, they must be considered as tolerably correct data, from which to draw both general and particular conclusions.

The resident Engineer of Kingstown Harbour, the late Mr. Thomas, superintended the operations, and his report to the Board of Public Works upon the issue of the experiments, I have been permitted to submit for the information of the Institution.

He reports as follows:—"The masonry of the leaning wall, Section A, and the earth filling at the rere, were commenced on the 20th October, 1834, and proceeded "*pari passu*," until the wall was carried to its full height.

At this date (31st December) the wall remains unaffected by the lateral pressure of the earth filling, although kept to its full height, from time to time, as subsidence occurred.

"The masonry of the sloping wall, Section B, was commenced on the 20th October, 1834, and was carried to its full height on the 27th of the following November. The earth filling at the rere was begun on the 20th of November, and completed on the 6th of December. The deficiencies from subsidence in the filling were made good, from time to time, as in the preceding case. Since the completion of this section, the slope in front is diminished 2½ inches, and there are some slight fissures on the face, indicative of instability."

"The masonry of the counter-sloping wall, Section C, was commenced and completed, concurrently with Section B. The earth filling at the rere was commenced on the 26th of November, and on the 6th of December, when the filling had attained the height of 17 feet, the wall was overturned." The Overseer reports:—"At one o'clock, P.M. the counter-sloping wall fell, the filling 17 feet high behind the wall; it overhung 10 inches, was greatly convex on the face, and rending in every direction: it overhung 5 inches in the first 5 feet of the height. In falling it burst out, at about 5 feet 6 inches from its base; and two thirds of the wall, from the top downwards, for its full length, kept in an upright position, until it reached, and was crushed on the ground." See Diagram, Figure 3.

"The masonry of the rectangular wall, Section D, was built at the time Sections B and C were erected. The earth filling at the rere was commenced on the 20th of November, and on the 6th of December, when it had attained the height of 17 feet, this wall was also overturned." The Overseer reports:—"At four o'clock, P.M.

the rectangular wall fell, the filling 17 feet behind the wall, it overhung 1 foot 6 inches: in convexity on the face more than 4 inches; it fell like a board, having increased in the overhanging from 1 foot, to 1 foot 6 inches, from half past three to four o'clock, when it fell." See Diagram D, Figure 4.

As a daily report of the progress of the work, and the state of the weather was considered of importance, the attention of the superintendent was particularly directed thereto, and I am therefore enabled to supply the Institution with the following Table, showing the height, to which the clay filling was carried, each day, during the progress of the work, and also a diary of the weather.

Dates. 1834.	A		B		C		D		State of the Weather.
	Ft. In	Ft. In	Ft. In	Ft. In	Ft. In	Ft. In	Ft. In	Ft. In	
Nov. 7	—	5. 0	—	—	—	—	—	—	Dry.
„ 8	—	7. 0	—	—	—	—	—	—	—
„ 19	—	11. 0	—	—	—	—	—	—	Rain.
„ 20	—	14. 0	—	—	—	—	—	—	Do.
„ 26	—	—	2. 6	2. 10	4 0	6. 4	4. 0	5. 6	Dry.
„ 27	—	—	3. 0	4. 9	7. 0	7. 6	6. 0	7. 0	—
„ 28	—	—	6. 0	8. 0	7. 9	8. 0	7. 0	8. 4	—
„ 29	—	—	8. 0	11. 0	8. 0	9. 9	8. 4	8. 4	—
„ 30	—	—	10. 8	—	9. 9	—	8. 8	—	—
Dec. 1	—	—	10. 8	11. 6	9. 9	10. 2	8. 8	9. 9	Much rain during night
„ 2	—	20. 0	11. 9	12. 0	10. 4	11. 4	10. 2	10. 6	Rain during night.
„ 3	—	—	12. 0	13. 0	11. 4	11. 6	10. 6	13. 0	Dry.
„ 4	—	—	12. 9	12. 6	11. 0	13. 8	12. 6	13. 8	—
„ 5	—	—	12. 6	13. 6	13. 3	14. 4	14. 8	15. 4	—
„ 6	—	—	15. 6	20. 0	15. 3	17. 0	15. 3	17. 0	—
„ 7	20. 0	—	20. 0	—	Fallen.		Fallen.		Much rain during night

From the arrangement of the several walls, it may be perceived that the weight of the filling could not have been entirely exerted upon the back of the retaining walls,

as the divisional walls must have relieved them, to a small extent, of some of the weight to which, otherwise, they would have been subjected; but, as each wall was similarly circumstanced, being alike affected by the same cause, their relative merits remain the same, as if the experiments upon each had been conducted in a separate locality, but under the same circumstances.

From the results of these trials, the most suitable form (of those experimented upon) for retaining walls, has been satisfactorily ascertained, and the comparative merits of curvilinear, and irregularly battering walls may, without difficulty, be deduced therefrom, being but compound forms of those which have been submitted to the test. The mean thickness adopted was also proved to be (as had been anticipated) the least which could possibly support the weight: but it is not to be understood, that this can be taken as a general rule for walls of any height, as in low walls, a mean thickness of one-sixth the height would be found much too weak, while in exceedingly high walls, this sectional area would be stronger than necessary.

The angle of repose, which the filling may assume, must also be a guide in the consideration of the proper section, as, of course the more this angle is increased, the less the mean thickness of the wall will be required. And in many cases, artificial means may be resorted to with advantage: thus, the filling being carried on concurrently with the wall, and well rammed down, is caused to assume a greater angle of repose, than it would naturally; consequently, the pressure on the wall will be diminished, and the sectional area required will be less than under other circumstances. By judicious management, in some cases, retaining walls may be constructed less strong than either theory or ordinary practice points out; for

instance, in building a high quay wall, which is subjected to the ordinary pressure from behind, but which has also to support the vertical weight of the wall of a store-house or other building, it is by no means necessary, that it should be constructed as strong as would be required to resist the horizontal thrust of the filling behind only, as then a heavy expenditure would be incurred in providing against a force, which, when the superincumbent structure is raised, will be in a great measure counteracted; but if, while being built, the retaining wall be supported by planks and shores on the face, until the superstructure has been raised to some height, and also until the filling has been, to some extent, consolidated, the supports may then be removed without the slightest apprehension of a downfall.

The system of shoring during the progress of the work may be well applied in the case of most retaining walls, but especial care should be taken as to the extent to which this practice of economising may be pursued, as the Engineer should ever bear in mind, that though, by keeping his course, he may sail clear of Scylla, yet Charybdis still lies before him.

As these remarks have been deduced from experimental investigations, I have refrained from entering into any theoretical consideration of the question; but it is not to be concluded from this, that I undervalue the importance of theory: on the contrary, I consider theoretical knowledge to be of the greatest utility, when accompanied with practical experience.

[May 27th, 1845.]

RICHARD LANAUZE, ESQ. C.E. Newcastle, Co. Limerick, was admitted a Member, and THOMAS HUTTON, ESQ. Summer Hill, an Associate of the Institution.

The following communications were read :—

"*On the* HISTORY AND CONSTRUCTION OF COFFER-DAMS; *with a brief description of an entirely new contrivance, proposed to be substituted in the construction of the foundations of Bridge Piers, in deep water, and other circumstances of difficulty;*" by WILLIAM FORSYTH, ESQ. C.E. Associate.

THE history of Coffer-dams is intimately connected with that of bridge-building, as they have been chiefly, if not exclusively, until a recent period, used in the construction of the foundations of bridges, built over rivers of such depth as to require their aid to enable the workmen to excavate to a firm and solid foundation; and to build the piers and abutments dry. But although there remain many magnificent specimens of ancient skill in this department of building, which for boldness of design, and solidity of construction, are scarcely surpassed by the most splendid modern structures, history is silent respecting the manner in which the operations were carried on, and the means devised for overcoming the difficulties in the execution. One of the earliest writers on the use of Coffer-dams, whose works are extant, was Alberti, who, in Chapter vi. Book 2, gives the following directions:—" Make the foundation of your piers in autumn, when the water is lowest, having first raised an enclosure to keep off the water, which may be done in this manner: drive a double row of stakes, and fill up the hollows between the two rows, with rushes and mud, ramming

them together so hard, that no water can get through; then whatever you find within the enclosure, water, mud, sand, or whatever else is a hinderance to you, throw them out, and dig till you come to a solid foundation."

These brief instructions are, perhaps, the earliest description, on record, of a Coffer-dam, and although imperfect in design, and simple in construction, when compared with the more perfect dams of modern times, it contained the elements of all succeeding structures of the kind.

The inefficiency of these early temporary structures, and the imperfection of the hydraulic engines then in use, for pumping out the water, and keeping the interior of the dam dry, probably tended greatly to prevent the frequency of their use; hence in the majority of old bridges, now or recently in existence, it is evident from the manner of constructing the platforms on which the bases of the piers and abutments rest, that Coffer-dams have been altogether dispensed with. In this case numerous piles were driven at a short distance apart, all over the site of the intended pier or abutment; their heads were cut off level with the summer water, and connected by cap-sills—sometimes in two or three layers crossing each other at right angles—and the spaces between the piles and cap-sills rammed full of rubble stones, and on this platform the masonry was commenced.

To prevent accident or injury to the bearing piles, as far as possible, immense, unsightly piles of stones, called "sterlings," were placed all round the artificial foundation thus constructed; and these sterlings were more or less perfect, as circumstances demanded, being sometimes bound together with a framing of timber, and a grillage placed in the space from sterling to sterling, and the interstices paved with stones.

The foundations of the old London bridge were a memorable example of this mode of construction, and many others are still in existence.

I merely purpose at present to allude to some works recently executed—some that have come under my own observation, and a few that have been constructed under my own directions.

I shall first advert to the Coffer-dams used by Perronet, in constructing the foundations of the Neuilly bridge, and this I do, not from any peculiar excellency which they possessed, but because they were chosen as the model of the dams for constructing the foundations of a recent work of considerable magnitude, and under circumstances of much difficulty.

The very limited number of publications containing practical illustrations of Coffer-dams, and other contrivances made use of in the erection of large bridges, in sufficient detail to enable the artizan to reconstruct them, has frequently placed those who have been called to execute similar works, and who may not have been practised in them, in circumstances of peculiar difficulty. When such is the case, they have either had to go through the whole process of invention, construction, and trial, subject to many and severe disappointments, or adopt such models as have been published. It therefore often happens that inferior models are selected. This deprives the Engineer of the assistance to be derived from the many skilful inventions of talented individuals, and the immense advantage that the efficiency of these inventions has been fully tested in the execution of the works for which they were particularly designed: and of the numerous subsequent improvements which have been made in them, from a practical knowledge of their work-

ing, because no proper description of them has ever been published, and they are therefore unknown, except to those immediately concerned in their construction and use. This certainly has the effect of throwing the individual so circumstanced, back for several ages, and depriving him of the advances that have been made by his immediate predecessors, or contemporaries, in the same department of engineering.

Perronet's dams were constructed as follows:—two rows of round timber guage piles were driven about 6 feet apart. To each of these rows of guage piles two or more tiers of double walings, according to the depth, were bolted, a space being left between each pair of wales in the same tier, equal to the thickness, and for the reception, of the sheet piles, which were planks of thickness suited to the magnitude of the coffer which was filled with puddle. The two rows of guage and sheet piles were connected by bracings, to counteract the pressure of the puddle. Before the puddle was placed in the coffer, the loose material of the bottom was dredged with the spoon and bag, until the solid rock was reached, to prevent the water finding a passage through any loose stones or other matter that might remain under the puddle. This was properly the Coffer-dam. The stays, strutts, and braces applied to give stability to it, and assist in resisting the pressure to which it was subjected, were merely auxiliaries, and their position and number varied as circumstances demanded.

The Coffer-dam to which I alluded above, and of which Perronet's was the model, was that used at the Potamac Aqueduct, United States of America, and of which a description is given in the London Engineers' Journal. The work was under the direction of Captain Turnbull,

who says that the Contractors of the work attempted to reach the foundations of one of the piers with a dam of a very novel construction. This dam was cylindrical, 80 feet in diameter; two circular curbs were formed, having their exterior diameter equal to the interior of the cylindrical sheet piling. These curbs were secured in their places by guage or guide piles, and whole baulk sheet piles, properly jointed, were driven round the curbs, there being no outer row of piling, nor any puddle. It was hoped that the pressure from without would so effectually compress the sheet piling as effectually to exclude the water. This dam proved a total failure, as after repeated attempts with the pumps, the water in the inside of it was not perceptibly lowered.

The contract being forfeited, the execution of the works was placed under the entire direction of the Engineers, who selected Perronet's dam, with a few modifications, as their model; and the sequel proved that the choice was not a judicious one. The first dam constructed occupied a position where there were 18 feet of water, and 17 feet 4 inches of mud, together, 35 feet 4 inches to the rock on which the masonry of the pier was to be founded.

The inner row of guage and sheet piles were 40 feet long, and driven to the rock, and the outer row 36 feet long. The guage piles were of oak, about 17 inches in diameter, and 4 feet apart in centre. The outer row was 15 feet distant from the inner row. The sheet piles of pine, 6 inches thick. The outer guage and sheet piles were not driven to the rock. The two rows were connected by numerous braces of timber and iron. The coffer was much too wide; consequently the pressure of the puddle damaged the outer system of piling, and threatened its destruction. But the greatest oversight

was, that the mud and sand in the coffer, after the piles were driven, was not dredged out to the rock before the puddle was put in, and the consequence was, that where the mud in the interior of the dam was being excavated, the great pressure on that under the puddle in the coffer forced it into the dam, between and under the inner sheet piles, occasioning a series of very discouraging disasters; and the great body of puddle becoming consolidated, did not in all cases immediately follow the mud, but left large passages for the water to enter and fill the dam.

These irruptions carried large quantities of sand into the dam, and choked the pumps, and thereby broke, and deranged their gearing, and the steam engine.

This state of things continued until the puddle had settled down and rested on the rock all round. It may, however, be observed, that if the mud in the coffer had been entirely removed before the puddle was put in, or the dam shored, the enormous pressure of the immense quantity of puddle on the unprotected state of the sheet-piling, together with the very defective principle of construction adopted, and the great depth would have entirely destroyed the dam.

There is a description of dam constructed on a different principle to which I shall afterwards refer, that would have obviated many, if not all these difficulties and expensive delays.

A dam of very easy construction has been sometimes used when the bottom has been firm and tenacious, and when the masonry has rested on an artificial foundation so placed as to require little excavation. A double row of guage piles are driven all round the enclosure for the pier, at such distances as may be sufficient for the width of the coffer, each row connected or bound together with

horizontal wales on the side next the enclosure of the inner row, and the side next the rise of the outer row, and the bays or opes between these two guage piles in the same row closed up by sheets or leaves of planks, jointed and secured together by transverse bars on the land, previous to their being brought to their intended position. The aggregate breadth of the planks joined together being something more than the depth of the water, and their length equal to the distance between centre and centre of two adjoining guage piles; or it may be from the first pile to the third in the same row, passing the second and enclosing two bays. These leaves are simply placed against the guage piles, the planks being in a horizontal position, the two rows of guage piles connected with braces, and the coffer filled with puddle in the ordinary way. A Coffer-dam constructed something like this was used at Gloucester bridge.

A dam of this description may be successfully used when the bottom is stable, and no risk of its being pressed from under the puddle into the dam and causing leakage.

I forbear to enter into any description, or make any remarks on the dams used in the London bridge, more than to say, that they have been repeatedly laid before the public in sufficient detail for their reconstruction, if necessary; but that their immense cost almost imposes a veto on their ever being used in any other locality, as it is not very probable that the necessary amount of funds for the construction of similar dams will ever be placed at the disposal of the provincial Engineer.

I now refer to a dam which has been extensively and successfully used—in tidal rivers especially—as it effects a considerable saving in timber and labour. First, a row of whole baulk guage piles are driven at 10 feet apart in

the clear, of sufficient length to stand when driven about 2 or 3 feet above high water. On the side of these most remote from the enclosure, two or three tiers, as the case may be, of double wales are bolted to receive and sustain the sheeting piles which vary in thickness from 4½ to 9 inches as circumstances demand, and the same length as the guage piles. Some diversity of opinion also exists respecting the manner of placing the wales. Some place them on the side of the guage piles next the enclosure, and fill up each bay with the sheet piles, making the guage pile serve as a sheet pile, and finishing each bay with a taper key. But these key piles are difficult to fit, and cause much delay and waste of timber—never drive well, in nearly all cases being either broken or forced out of the range.

The most approved way is to place the wales as first stated, and drive the sheet piles from two extreme corners or ends of the dam along one side, and close by one key pile at the meeting. The sheet piles must be roughly jointed and driven closely together. The width of the coffer need not exceed 6 feet. The outer guage and sheet piles are much inferior to the inner ones, and only rising a little above low water; the sheet piles may be such as are rejected for the inner row or any other rough planks. The use of this row is merely to support the puddle from the bottom of the river up to low water—the two rows are braced with wood or iron, or both in the usual way; but it may be observed, that no brace or ties should pass through the puddle, as it invariably happens that a channel is made under every one, so passed, on the subsiding of the puddle, and by which the water enters the dam; these channels are extremely difficult to reach or stop up, and are a constant source of annoyance. When the

puddle has reached the surface of low water, the outside wales of the inner row of sheet piles are removed, and the seams or joints caulked with oakum, in the same way as the seams of a ship's planks, from the top edge of the dam down so far as low water will permit. The upper wale or wales, (which depends on the height of the dam over low water,) are then replaced and firmly bolted, but the lower wales are not replaced, because they would form a ledge for the puddle to rest upon, and consequently, a cavity or channel would be made under them. The puddling is then carried up 2 or 3 feet higher than low water, or the limit of the caulking, being sloped up from the outside against the inner sheet piling and so covering, or overlapping the caulking about 2 or 3 feet.

The internal shoring or bracing, to prevent collapse as in other dams.

There is a saving in this dam, as compared with dams usually constructed, having the inner and outer systems of piling nearly similar, as 5 to 7. The quantity of puddle to be removed, after the dam has served the purpose for which it was designed, is much smaller, and its diminished pressure does not threaten, much less affect, the demolition of the structure itself.

If Captain Turnbull had adopted a dam of this construction, he would have effected a great saving in expenditure, and relieved himself from much anxiety.

Dams of this kind were used at Whiteby bridge in Yorkshire: the Ribble bridge at Preston in Lancashire: the suspension bridge over the Tyne at Scotchwood in Northumberland, and many other places. At the last mentioned bridge, the piers for supporting the suspension chains were raised on platforms, and bearing piles driven through a great thickness of soft sand. It, therefore,

became necessary, to groove and tongue the inner sheet piles, to prevent the sand being forced through below the puddle in the coffer, and so necessary was this precaution, that in one instance, a sheet pile was slightly shattered, by taking a wrong direction in driving, which caused an opening in the joint, and at high water, when the pressure on the dam was greatest, the sand was forced through; and a passage being once effected, sand and water were driven in with such force as to rise in a jet nearly as high as the top of the dam, and by which it was very soon filled; nor could it again be emptied until the defective part was counterlined, by driving other sheet piles against it on the inside. The sheet piles were 9 inches thick, and grooved and tongued 2 inches square.

The Coffer-dams used in the erection of Athlone bridge were on the same principle, as nearly as circumstances would allow: there being no tide, and the rise and fall of the flood water not exceeding 2½ feet, the difference in height between the outer and inner piling of the coffer was only small, and the puddle was raised as high as flood line, there being no caulking.

The outside piling was, however, much inferior to that of the inside, and a great proportion of it native timber. The depth of water at the western abutment of the stone bridge, and the eastern abutment of the swivel arch, was about 15 feet. The wales of the inner row of sheet piles were whole baulk, and five tiers in height. A rather novel mode of placing these wales was adopted, very successfully, in the construction of these dams. The usual way of attaching the wales is to bolt two or three double tiers, according to the height of the dam over the water, to the guage piles; the space between the wales being equal to the thickness of the sheet piles; the lower,

or lowest tier placed as low down on the guage piles as the water will allow.

It is well known to all persons concerned in the erection and use of structures of this kind, that however straight the wales may be placed, and however great care may be taken in inserting the sheet piles, it is impossible, in driving, to keep them at all in the same plane on either of their faces; but from causes, over which there is little or no control, they will depart from the intended plane of their inner faces more than their own thickness, and this departure will be generally proportionate to the depth of the water, or distance between the lowest tier of wales and the bed of the river.

Inattention in shoeing the piles, placing them more to one side than another, by which they have a draught towards that side, and encountering boulders when being driven, cause them to be forced out of the intended plane; thus large vacancies are left between them, instead of their forming a continuous sheet, and through these openings the puddle and material of the bed of the river are forced towards the inside by the pressure from without; and channels, resembling covered drains, are also formed beneath the puddle, of such magnitude as to fill the dam with water, in spite of every effort to prevent it. This was frequently the case at the Potamac aqueduct, as appears by the Engineer's reports.

There is also another evil resulting from this irregularity of the sheet piles, that when the water is lowered to such a depth, that it becomes necessary to support the sheeting piles, lest in their unprotected state the pressure from without should prove more than they are able to resist, those that project inwards from the intended or general plane of the inner faces, must be adzed away, to

admit of the wales affording support to as many of them as possible, and this greatly weakens those that require cutting. In many instances it has been found necessary to cut them through altogether.

To obviate these difficulties as far as possible, and to save time, and to give facility to the placing of the shores and stays in the dam, when the water was being pumped out, and likewise to give more support to the sheet piles, and greater strength to the dam generally, than can be done in the ordinary way; the five tiers of wales were all placed at the same time, the lowest resting on the bed of the river.

The manner of accomplishing this was as follows:—When the guage piles were driven, a guide pile of half baulk was placed opposite each of them on the side next the river; this guide pile had a square block secured to it, about 3 feet from its lower end, by two transverse bars or guards, about 2½ feet long, spiked across the edge of the guide pile and block, their ends projecting beyond the block about 15 inches. The projection of the block from the face of the guide pile was equal to the thickness of the wales; in placing the guide pile, the two guards were made to embrace the guage pile on each side, and the block to bear against its outer face. The guide pile was then run down to the bottom, keeping the block in close contact with the guage pile; a few light strokes were then given to it with the ram, until the block rested on the bed of the river. A temporary brace was then spiked across the tops of the guide and guage piles, to preserve their parallelism throughout.

When all the guide piles were thus placed and secured on one face or side of the dam, the wales were brought alongside, and the lowest tier run in between the guide

and guage piles along the whole range. Upright distance-pieces were then spiked to the wales, on the side next the enclosure, and in the bays or spaces between the guage piles; then these upright piles were also notched on to the wales to make them more effective. The distance between the two notches being equal to the intended distance of the two tiers of wales apart in the clear, vertically. Diagonal pieces were also spiked to the wales, inclining in opposite directions, and when this was done, the rams were lowered down, and rested on the wales, by which they were sunk until the upper notches of the uprights were just as much under water as allowed the second tier of wales to be run in between the guage piles and guides, and the uprights and diagonal braces spiked to them.

The diagonal braces were mere slabs, and were for the purposes of giving rigidity to the system, and preserving the uprights in their proper position, by counteracting the tendency of the wales to escape end-ways from their intended position. A second series of uprights and diagonals, similar to the first, were then spiked to the second tier of wales, and the weight of the rams placed on them, until they were sunk sufficiently to admit of the third tier of wales being introduced, and so on, until the whole were in their proper position, the lower tier resting on the bed of the river. The two upper tiers being accessible, were bolted to the guage piles, by which the whole was effectually secured.

The guide piles being of the same thickness, the sheet piles admitted of two tiers of half baulk wales being bolted on the outside, opposite to the two upper tiers of the inside whole baulk wales, and a space was thus reserved sufficient to receive the sheet piles. In shoeing the sheet piles, they

were made to have a slight draught towards the inner wales, as well as towards the last driven pile against which they were placed. This secured not only close joints, but contact with each of the tiers of wales, and gave firmness and reciprocal support to the whole dam. When a sufficient number of sheet piles were driven, to support the wales, the guide piles were forcibly withdrawn, being of no further use in their present locality. This contrivance was completely successful, and although it was attended with a little trouble and delay in the execution, it amply repaid all, in the superior efficiency of the dam, and the great facility and saving of time in placing the shores and stays, when the water was being pumped out of the dam.

The next kind of dam, deserving of notice, is that intended to resist the pressure from without, independent of any shoring or cross stays. Various contrivances to effect this have been adopted, consisting of several rows of piles and coffers, the outline of the transverse section approaching to that of an embankment.

An example of this kind of dam, is that which was proposed to be used for the enclosure of the river wall, at the new houses of parliament. Here it was proposed to construct a coffer in the usual way, but instead of cross shores or stays, to resist the pressure from without, by a system of diagonal bracing.

The abutting points of the diagonal braces were supported by a pile of the same dimensions as a guage pile, and driven at a distance, and opposite to it, within the enclosure.

Before this abutment pile, as it may be called for distinction, was driven, the diagonal struts were to be secured to it by a strong screw-bolt, at the point corres-

ponding to the level of the bed of the river; when the pile should be driven, sufficient liberty was allowed in screwing them on, to revolve on the belt. When the abutment pile was driven in its intended position, the longest of the struts was brought to bear against the guage pile at the level of the upper wall of the coffer, made to fit tightly, and firmly secured by brackets and screw-bolts. The next largest was to be fitted at the second wale from the top in a similar manner. And lastly, a brace might be placed on the bed of the river, between the two piles to give additional support, if the resistance of the material composing the bed of the river, was deemed feeble. To retain the abutment pile in a vertical position, its top was to be braced horizontally to the top of the guage pile, and to give additional rigidity to the whole system, a tie bar was secured to the guage pile, before it was driven, at the point corresponding to the surface of the bed of the channel, and ultimately secured to the top of the abutment pile.

It is evident that the stability of this Coffer-dam, and its power to resist the pressure from without, would depend nearly altogether on the strength of a single screw-bolt, and it is well known, that it is extremely difficult to drive piles with braces attached to them without having the bolts broken, or the ends of the braces shattered by the concussion in driving. In the event of this being the case, the design becomes an entire failure.

But what is most to be dreaded is, that the damage done to the bolt or braces might be unperceived and unknown, until the dam was subjected to the pressure, when the consequence must be ruinous in the extreme.

To obviate these defects, and avoid as far as possible any risk, I shall describe a dam bearing some resemblance

to this in form, and to be used for a somewhat similar purpose, that is, to enclose a large area without cross stays.

It was proposed to use this dam, to enclose the site of the new lock on the Shannon Navigation, at the town of Athlone, in the event of Mr. Mac Mahon becoming the Contractor for that work.

Instead of securing the diagonal struts to the abutment pile—which is 13 feet distant from the gauge pile—a separate frame is designed to fit the space between the two piles, this frame to slide down between them until it rested on the bed of the channel. The upright part of this frame which is against the abutment pile, has a concavity near its lower end, formed by its dimensions being there much greater. The end of the principal strut fits into this concavity, it being described by the same radius, that is the distance from the bolt, by which the lower end of the strut is retained in its assigned position, and forming what is technically called a rule joint. Two apron-pieces were to be placed horizontally across the lower part of the frame, and embracing its two uprights and the rule joint just described. These apron-pieces were extended, so as to enclose between their ends the guage and the abutment piles, and served as guides in lowering the frame to its berth. Horizontal braces were to connect the entire system, from the abutment pile to the exterior guage pile of the coffer, at their heads or upper ends. Where the frame should be lowered, it was proposed to fit the end of the main strut to the back of the guage pile opposite the upper wale, and apply a lever power to force it into close contact with the bed of the channel and the abutment pile at that level, and then secure it with brackets and bolts. When the water was lowered to the bed of the channel, the apron-pieces and

upright sides of the frame were then to be bolted to the guage and abutment piles, and secured with brackets where necessary. The apron-pieces now became ties, to retain the abutment of the main strut, and an excavation could be made round the abutment pile, in connexion with the excavation, or main tap in the centre of the enclosure, to allow the second or lower strut to be placed and secured. The system of bracing is now complete, and all the abutting points nearly perfect, and none mechanically depending on the cross strain of a bolt. Of course the distance of the abutment pile, and the number of struts and apron-pieces will depend upon the depth and resistance required.

There is a difficulty of great magnitude, very frequently encountered in the construction of the foundations of bridge piers and abutments, for which the Coffer-dam, however perfect, affords no relief: that is, the water from land springs forcing its way into the dam after the water contained within its enclosure is pumped out, and the pressure on the bottom removed. It almost always happens, in such cases, that the bottom is so feeble that a timber platform, supported on bearing piles, becomes absolutely necessary to carry the superincumbent building. It may be that no difficulty occurs in pumping out the water in the first instance, on the completion of the dam, but whenever the bed of the channel is disturbed, by the driving of the bearing piles, the issue of spring water into the dam overcomes the power of the pumps and suspends the works. This was remarkably the case at Athlone bridge, which stands on the upstream, or northern edge, of a gravel shoal, a continuation of an escar that rises to a great height on both sides of the river. The

site of the bridge was covered with a tenacious sandy clay of variable thickness, and when this clay was cut through by excavation, or pierced by pile driving, the rush of water into the dam was such as to fill it in a few minutes; although, previously to this, the quantity of water made in the dam was not sufficient to keep the pumps at work. The clearest proof was afforded that this water was from land springs, by all the pumps in the town, which are situated at a high level, being deprived of water when these ruptures took place.

Another interesting, though to us vexatious proof, was that all the foundations communicated with each other underneath the bed of the river. This was first ascertained by a well, constructed at the rere of the east abutment, at the request of the Town Commissioners, the surface of the water in which fell between 2 and 3 feet, when these ruptures in the enclosures of the pier dams took place. This circumstance is the more annoying where it exists, as no precautionary means can be adopted to guard against it, and an evil generally accompanies it, that the materials composing the substrata of the bed of the river channel are intermixed with a large proportion of sand, which often lies in masses and is carried into the dam by the spring water; and large cavities being formed, the crust of the channel is broken and falls down, forming a direct communication between the river and the inside of the dam.

A contrivance has been used, which is calculated in some measure to overcome these evils, called a caisson. The foundations of Westminster and Blackfriar's bridges were constructed by the aid of these machines, of which many descriptions and drawings are before the public. So far as regarded obtaining a well constructed platform

for the masonry to rest on, they were certainly successful, and there was an entire freedom from all the annoyances and delays attendant upon a leaky dam; but these platforms cannot easily be sunk much under the surface of the bed of the channel, and consequently if the river be rapid, or subject to great mountain floods, there is much danger that they may be undermined by the force of the current, unless protected by the unsightly sterling. The greatest difficulty, however, attending their use is the obtaining a level surface, or bed, for them to rest upon, for if the bearing of the platform on the bottom be not continuous, settlements will very likely be the result, when the weight of the superstructure comes to act upon them, and will necessarily cause great derangement in the masonry. A memorable instance of this is recorded in the history of the erection of Westminster bridge. When it was approaching completion, one of the piers settled down suddenly, and caused such derangements as made it necessary to reconstruct a part of it. It was supposed, at the time this took place, the settlement arose from the bed of the channel being too feeble to support the superincumbent weight; but in the execution of the recent repairs, it has been discovered that the descent of the pier was owing to a very different cause. It appears that the sinking made in the bed of the channel to procure a level site for the bottom of the caisson or platform to rest on, was too small in its extent, therefore the platform rested on the sides, or slopes of the sinking, leaving a hollow underneath it, and it had borne the weight of the pier by its own strength, until the superstructure was added; the insistent weight then became too great for it, and it suddenly yielded, until it reached the level surface prepared for it.

An abortive attempt was made to found a bridge over

the Lower Bann river, about the year 1784, a short distance below the present bridge at Toome, by means of a rude contrivance of this kind. It appears that the caisson constructed for the purpose was of too small tonnage to bear the weight of the necessary quantity of masonry, to raise the pier over low water; it was therefore suspended by a number of tackles, from a row of piles, driven around the site of the intended piers, and by which it was proposed to lower it gradually down, as the masonry was raised, until it rested on the bottom. But in performing this operation some of the tackles gave way, and the masonry being upset, it tore the machine in pieces, and fell piecemeal to the bottom; the liberated timbers also, obeying the laws of gravitation, floated quietly down the stream. Whatever advantages caissons may have over Coffer-dams, it appears the disadvantages and risk attending them have been so great, that by common consent their use has been abandoned; and no doubt their immense cost, when properly constructed, has not been the least weighty objection to them.

It was remarked, that the simple dam of Alberti, however rude and imperfect, contained the elements of all subsequent structures of the kind. It is true that superior mechanical skill has been exhibited in the construction of modern Coffer-dams, yet the principle, with very little alteration, is the same, and the chief superiority which they possess is not so much in themselves, as in the vastly superior hydraulic machines, and the invention and improvement of the steam engine, by which they are now freed from water. The extraordinary exhibition of the inventive faculty which so distinguishes modern times, has been but little directed towards the introduction of new principles in the construction of machines to surmount

the difficulties attending the building of bridge piers in deep water, with facility and despatch, and at a moderate cost, notwithstanding the vast importance of this branch of hydraulic architecture. The improved diving bell has been successfully used in building piers and wharfs for the protection and accommodation of the naval power and wealth of these kingdoms; but it has not been considered well adapted for building the foundations of bridges. In the former case, immense piles of masonry, composed of huge blocks of squared stone, possessing sufficient gravity to sustain the moles of rubble stone, or earth filling, and to resist the fury of the storm, are the chief features in that department of building; and little aid is required from the use of mortar or cement. Indeed the application of mortar, in building submarine foundations with the diving bell, is not attended with the advantage that might be expected, as the very act of spreading it, to bed the stone, subjects it to the action of the water, so as to detach the finer and lighter parts of the lime from the sand, and while the latter remains on the proposed bed, the former is held in suspension, and floated away. If the mortar could be emptied out of the tubs in masses, and left undisturbed, it will set perfectly, and rapidly, but this is wholly impracticable; and in nearly all cases, where I have seen it used, after the bed has been cautiously and carefully spread, and when the turbid water passed away, it was seen that very little remained, except the sand that had been used in the composition of the mortar.

In building the piers of bridges, it is highly necessary that they should be firmly cemented throughout, from their limited dimensions, and the highly important duties they have to perform. There is also much greater accuracy required in their position and fitting.

There is yet another hinderance to the use of the diving bell in these structures; in most cases the current of the river would act with such power on the bell as to make it unsteady, so that little could be satisfactorily done, and where artificial foundations of timber are required it is totally inapplicable.

This subject has engaged my attention for many years, and from my personal experience in this department of hydraulic architecture, I venture to put forward a proposition that may probably appear rather extraordinary, but which I have no doubt, if carried into effect, would alleviate the greater part, if not all the difficulties which I have adverted to above, and at a smaller cost than the outlay required for a dam of the ordinary construction, and on the most economical scale; especially in localities where the bed of the channel resembles that in the site of Athlone bridge.

I propose that the site of the intended pier be enclosed with a structure, chiefly of sheet iron, resembling a gigantic diving bell, constructed after the following manner. The bed of the channel in the intended site to be dredged to the level of the under side of the first course of masonry, or the underside of the timber platform, as the case may be; then, if a timber platform be required, I propose that the bearing piles be driven from a suitable scaffolding, supported on whole baulk piles, well driven into the bottom all round the intended enclosure, the principal use of these piles to be afterwards described. On this scaffolding the exact position of each bearing pile can be accurately marked, and if carefully lowered to the bottom, there will be no difficulty in keeping them in line for receiving the capsills. It will be readily perceived that, in following this plan, the piles must be longer than

what is proposed to be driven, by a quantity equal to the depth of the water, so that when they are driven down until their heads be level with the water's surface, the specified length will be driven into the bed of the channel. This method of driving piles has been adopted in several instances, where common dams were used, and it was found that the waste in the over length of timber, was doubly repaid in the saving effected, by dispensing with the pumping during the time they were being driven, and the vastly greater facility in driving, compared with having the piling engines on the bottom in the dam, which is then crowded with cross stays and bracings. When the bearing piles are all driven, and the piling engines removed, a timber frame of the interior dimensions of the structure, previously prepared and fitted, is to be brought, and the pieces joined together and secured by strong tackles from the piles before mentioned, over its intended position. The scantling of this frame to be from 9 to 12 inches. To this frame the first course of plates is to be bolted, and to each other in the manner of joining the plates of steam boilers, only screw bolts are to be used instead of rivets. The bolts to be inserted from the inside, and screwed on the outside; the angles secured with angle iron. When this shall have been done, the seams and heads of the bolts are to be covered by stripes of canvass, about 4 inches broad, covered with caoutchouc cement to prevent leakage. Uprights are then to be placed in the angles, and along the sides and ends, resting on the bottom timber frame at intervals of 5 or 6 feet, and secured to the plates by plate iron brackets and screw bolts; their height to reach to a second timber frame, placed about half way up the second course of plates. Temporary angle braces and cross stays must

now be made fast to the timber frame, in such positions as will clear the bearing piles, to keep the structure in proper form. These are to be removed when all is completed, and the water expelled. The whole is now to be lowered equally by the tackles, until the upper edge of the plates is within a few inches of the water's surface, and the second course of plates commenced, by fixing their lower ends to the first course and to each other, with screw bolts, in the same manner as before, and the horizontal, and vertical seams, covered with canvass and cement, carefully connected so as to leave no perforations.

The second horizontal timber frame is now to be placed on the heads of the uprights, and secured to the sides by plate iron brackets, and to the uprights by bar iron angle straps and screw bolts, and a second tier of uprights placed and secured in like manner. These last uprights to be of such a length as to reach within 2 feet of the top of the structure. The whole to be now lowered until the upper edge of the plates is again within a few inches of the water's surface, and a third course of plates fixed; and if it be necessary, to complete the intended height, the same operation is to be continued in fixing a fourth course of plates, securing all in the same way with brackets, bolts, canvass, and cement. The whole will now rest on the bottom; and a third frame of timber is to be placed on the heads of the uprights, and secured as before. It is intended that the sides shall be of such a height as to rise 6 feet over the surface of the water. Angle iron is now to be secured to the plates composing the sides and ends; and joists, of whole baulk timber, placed over each opposite pair of uprights, on the sides, and bolted to the horizontal timber frame. On these joists, the plates intended for the top are to be laid, and

strongly secured to them by plate iron brackets and bolts. The plates secured to each other and to the angle iron, with screw bolts, in the same manner as the sides and ends, and every seam and bolt-head, connected with the plates, covered with canvass and cement. In the top plates, circular perforations are to be made to receive lenses for the admission of light, similar to those used in the diving bell, and fixed in the same way, with glands, bolts, and luting. The number of lenses will be in proportion to the magnitude of the structure, and their own diameter.

The next thing to be provided, is the manner of keeping up a communication with the inside of the enclosure, without suspending the operations, when the water is expelled. The ends of bridge piers are usually rounded or pointed, especially towards the stream; this will leave a large unoccupied space in the angles of the sheet iron enclosure. In one of these I propose to construct a chamber, about 8 feet long, measured parallel to the side of the enclosure, and 5 feet wide, measured parallel to the end, and about 10 feet high; to be constructed of the same materials as the main structure itself. Angle iron must be fixed to the sides and top of the main structure, to receive the plates forming the side, end, and bottom of the chamber. These will have to be fixed after the water is partly expelled, as the bottom will be 4 feet under the water's surface. The entrance from without to this chamber to be in the top, and to consist of a valve, sliding in a frame, secured to the top; the valve to have a raised part round its edges, wrought true, to fit up against a corresponding true part on the frame itself; the part of the frame that supports the valve underneath, to have several screws with cross handles,

passing through it, so that when the valve is drawn over the opening, and the corresponding or opposing parts well supplied with an unctuous luting, it may readily be tightened up against the face of the frame, by a few turns of the screws, and made air-tight. The dimensions of the opening to be sufficient to receive the largest stone that may be required. Another opening, to communicate with the chamber from within, to be made in its end adjoining the side of the main structure, to be furnished with a slide valve similar to that described, with this difference, that its motion shall be vertical. The bottom of the chamber must be supported from the bottom of the river, that it may be strong enough to carry 4 or 5 tons without injury. The provision for expelling the water from the interior is simply applying the steam engine, usually provided, to work a powerful double blast air cylinder, fixed in a convenient position on the top of the structure, and the water is expelled from the interior out under the sides, by the air forced in, instead of being pumped out.

The manner of entering the enclosure, or of introducing a stone, is this: when the stone has been lowered into the chamber, and rests on the floor, the person entering disengages the tackling, draws forward the upper slide valve, and screws it up against the frame, then he opens a stop cock, fixed in the side of the chamber communicating with the interior of the enclosure, by which the chamber is filled with air of the same density as that within the enclosure; the pressure is now removed from the lower valve, which is raised up by a balance weight attached to it. He now enters the interior of the enclosure, and a short length of stage being erected inside, at the entrance from the

chamber, the stone may be rolled forward on rollers, until it can be laid hold of by the tackling inside the enclosure, and lowered to its berth. To leave the inside of the enclosure is just the reverse of this: the lower valve and stop cock are shut; a stop cock fixed in the top, and communicating with the outside, is opened, by which a part of the air escapes, until that within the chamber is of the same density as the surrounding atmosphere. The upper valve is then withdrawn, and an exit effected. This process may be repeated as often as a stone, or mortar, or any other material is required, without in the least interfering with the operations inside the enclosure. The apparatus proposed to be used for setting the masonry is on the same principle as the flat traversing frame and crab in common use, made as low as practicable to suit the locality, and supported on longitudinal road pieces, bolted to the uprights on the sides of the structure. I propose that a small opening, similar to the manhole of a steam boiler, provided with a door of the same construction, be made in the end of the structure, apart from the chamber, at which all the long timbers for capsills and planking, can be taken in before the water is expelled; so that the inconvenience of introducing them through the chamber may be avoided.

The bearing piles already driven, can now be cut at the proper level, the capsills placed, and all the other operations of planking, setting, &c. carried on without intermission, and the workmen effectually sheltered from the inclemency of the weather. There can be no danger arising from springs, or any risk of blowing up, as the pressure on the bottom still continues the same, and all incursions of sand are avoided. If it be thought necessary to defend the platform by sheet piles, they can be

driven by small ringing engines introduced into the inside of the enclosure. It is generally the case that concrete cannot be used between the bearing pile heads, on account of the streams of water issuing from the bottom, which wash away all the glutinous part of the lime, and leave only the gravel and broken stones; but here, there being no issue of water from the bottom, the concrete can be protected until set.

It is presumed, that the proposed manner of covering the seams with canvass and cement, will make the whole fabric perfectly water-tight, and should the cost of the cement be too great, asphalte will answer very well, but it is much more inconvenient as it must be applied hot. It is also presumed that there will be no risk to the lives of the workmen, for should the water rise in the inside, before they could effect their exit, there is such a large space open above water, and ample means of supporting themselves until they can make their way out, that they can scarcely sustain much injury. It remains now to enquire, whether the structure would retain its position by its own gravity when the water is expelled, or what aid may be necessary. Suppose the depth from the surface of the water to the lower edge of the plates to be 15 feet, the whole height would then be 21 feet, and take its length at 60 feet, and width 15 feet, it would probably weigh 30 to 35 tons. The upwards pressure would be equal to half an atmosphere, which on the area of the top would require a resistance equal to 400 tons, over and above the weight of the structure itself. This resistance is readily supplied, by placing about 200 stones, averaging 2 tons apiece, over the top. The provision made for supporting this weight by the uprights and joisting, is quite equal to the task; it is, however, probable

that if the bottom be soft, this great insistent weight would press the lower edge so far into it, before the water is expelled, that the escape of the water and air underneath it would be prevented. In that case, a part of the bottom under the position of its sides and ends, should be scooped out so as so facilitate the expulsion of the water.

To ascertain the time requisite to expel the water, suppose all tolerably air-tight, take the area of piston of the steam engine at 150 square inches, with a pressure yielding a disposable force of 20 lbs. per inch; the greatest resistance to be overcome by the blast cylinder is 7½ lbs. per square inch of its piston, and suppose that in both the velocity is alike, (220 feet per minute) and the diameter of air cylinder piston be increased, until the resistance equals the force of the steam piston, it follows that about 600 cubic feet of air, of equal density with the atmosphere, will be forced into the enclosure in that time.

The cubic contents of the enclosure are—

	C. feet.
Below the level of the water surface,	13,500
Above do.	5,400

It is a law in pneumatics, that the volume of atmospheric air, when under compression, is proportionate to the weight by which it is compressed. If a pressure equal to two atmospheres be applied, its volume will be reduced to one-half. In the present case, the greatest pressure to which it wiil be subjected is half an atmosphere, it will, therefore, require 18,000 cubic feet, at the ordinary density of the atmosphere, to occupy the former position of the water within the enclosure. The portion of the cubic contents of the enclosure, above the surface of the water, is

already occupied by air of the ordinary density of the atmosphere, and it only requires the addition of as much more as will increase its density to equal that below, which will be 1,800 cubic feet, together 19,800 cubic feet. at 600 cubic feet per minute; it will, therefore, take thirty three minutes to expel the water from the enclosure.

Comparative cost:—I stated that the weight of the structure would be about 30 to 35 tons.

Take it at 35 tons, at £30 per ton,.....	£1050	0	0
Timber, 1800 cubic feet, at 3s. per foot,....	270	0	0
	£1320	0	0

A dam of the ordinary kind will cost, 162 lineal feet, at £10 per foot, £1620.

"*On an* Improved Construction of Theodolite;" by George Yeates, Esq. M.R.I.A. Associate.

In the construction of this Theodolite, Mr. Yeates had endeavoured to secure great lightness and portability, combined with great strength and steadiness, while particular attention was given to the accuracy of the instrument.

To accomplish this, the following plan was adopted: The vertical arc usually placed under the telescope, for the purpose of measuring vertical angles, was done away with; and the telescope in its Ys placed close to the horizontal limb of the instrument. The centre of vertical motion of the telescope Ys, was placed at one side of this horizontal plate; and at the other, and opposite end, was attached a graduated arc, moving vertically with

the telescope, the vernier being firmly attached to the horizontal plate. By this means the vertical arc was of such a size, as to enable single minutes to be read with facility, with the naked eye; while the telescope being placed so low, and the instrument unencumbered with the heavy supports generally used, great steadiness was obtained.

The ordinary small levels of the azimuth limb of the instrument were also done away with, and one long and delicate level substituted. This was fixed, with adjusting screws, to the horizontal limb, parallel to the telescope; and at the opposite side a long and very delicately poised magnetic needle was fixed. This needle was not intended to read more than a few degrees at either side of the N and S line, the bearings being easily obtained from the azimuth circle of the instrument. The tangent adjustments and parallel plates are the same as those in ordinary use; the vertical arc is worked with a well formed rack and pinion.

The peculiar advantages of this construction were the position and delicacy of the level—admitting of great accuracy in the levelling of the instrument, (while in the ordinary instruments, the small levels on the horizontal limb are nearly useless) and also possessing the peculiar advantage that, from the manner in which it is placed in this Theodolite, the bubble is not disturbed from its horizontal position, when measuring either horizontal or vertical angles. When necessary to read angles of depression, it is only requisite to reverse the telescope in its Ys.

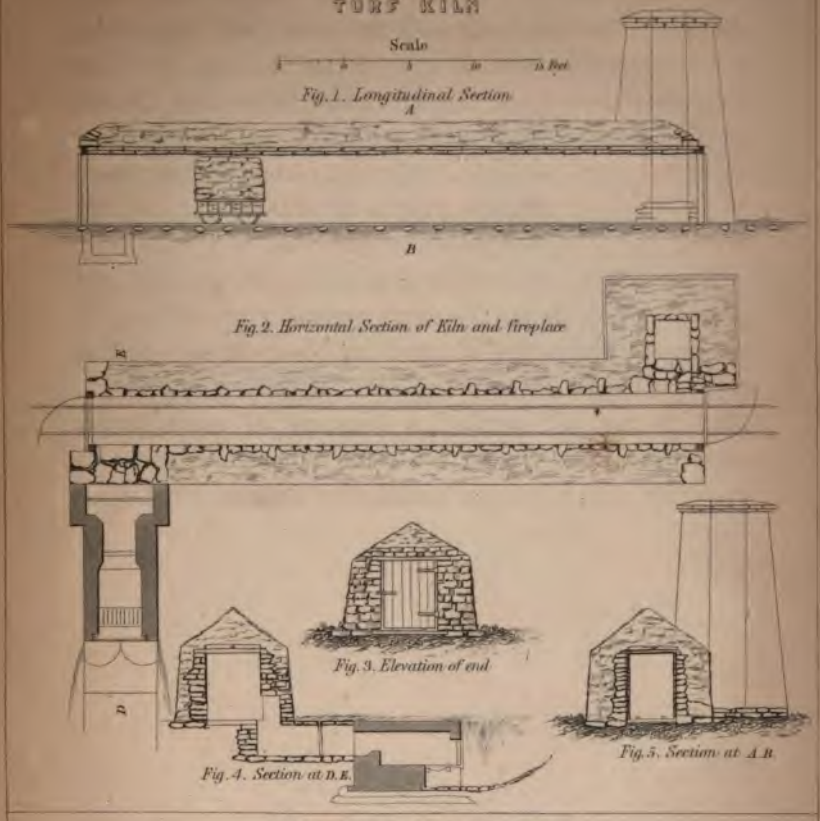
The instrument thus made with an horizontal limb of 4½ inches diameter, is equal in accuracy, for vertical angles, to one of the ordinary construction of 7 inches

diameter; while it is scarcely more than half the weight, and packs into a box of one quarter the size, and from its great compactness, it is much less liable to be affected by wind when in use. The bottom of the Ys also being carefully adjusted to the horizontal plate, the instrument is, for levelling purposes, fully as accurate as the ordinary levels, having telescopes of the same size.

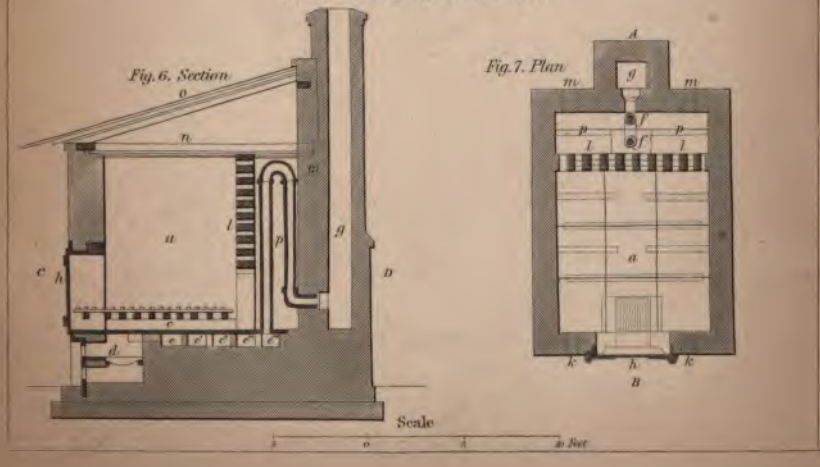
The Theodolite exhibited at a former meeting (see page 66) though on the same general construction, did not possess the means of repeating observations, and had also a telescope of smaller power. In the one now shewn, Mr. Yeates had applied a telescope of much larger diameter, giving greater light and power, and had also given the instrument the means of repeating.

W. PORTEOUS, PRINTER, WICKLOW-STREET.

TURF KILN



GERMAN KILN FOR DRYING TURF



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DESIGN FOR KILN

Robert Mallet. M.Ins

16

Fig. 1. Longitu

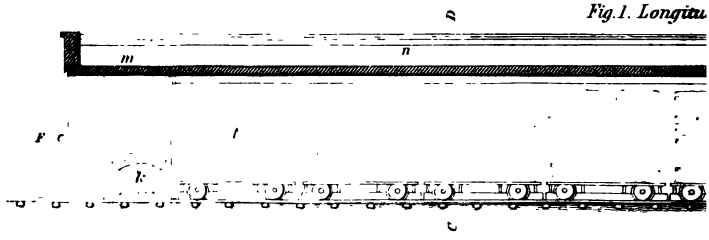
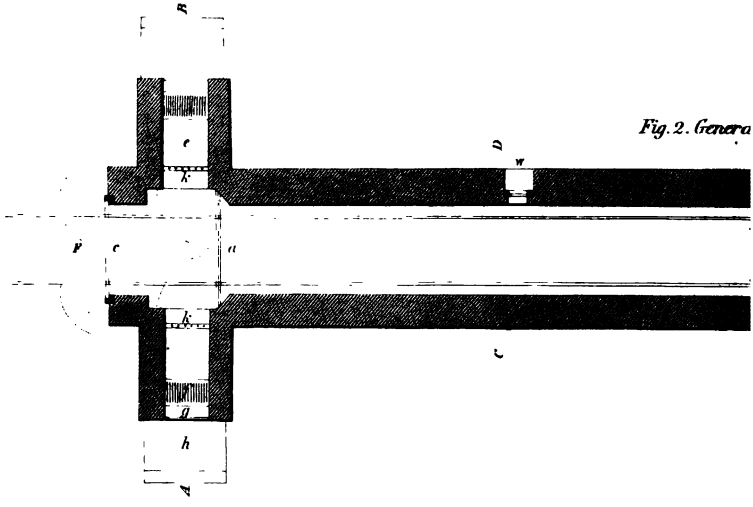


Fig. 2. Genera



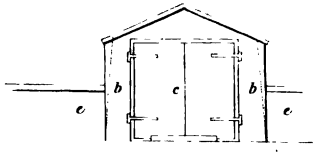


Fig. 3. Elevation of end at F.

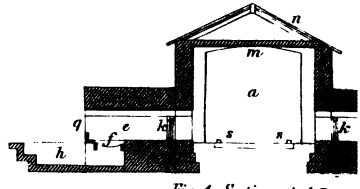
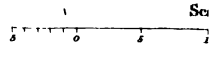


Fig. 4. Section at A.B.

Sc

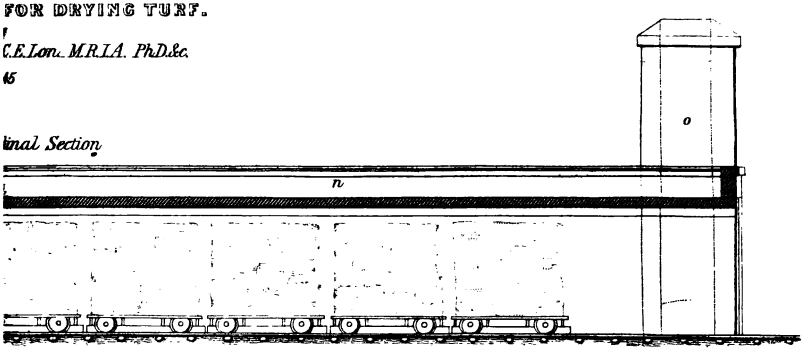


FOR DRYING TURF.

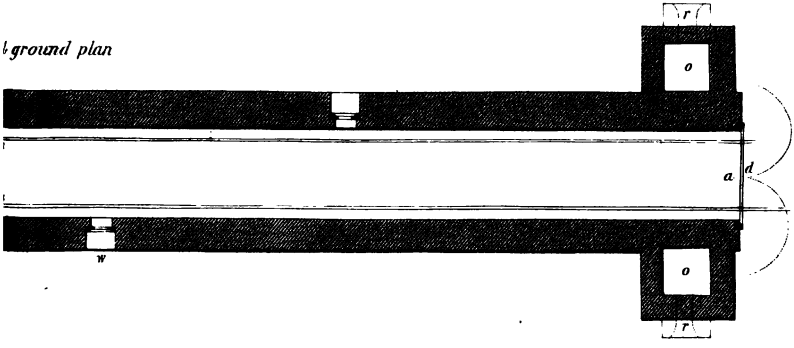
C.E.Lon. M.R.I.A. Ph.D.&c.

46

inal Section



ground plan



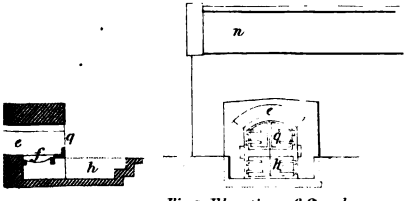


Fig.5. Elevation of fireplaces

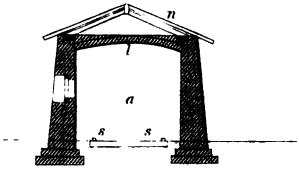


Fig.6. Section at C.D.

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MAC MAHON ON CENTRES.

Fig. 1. Athlone

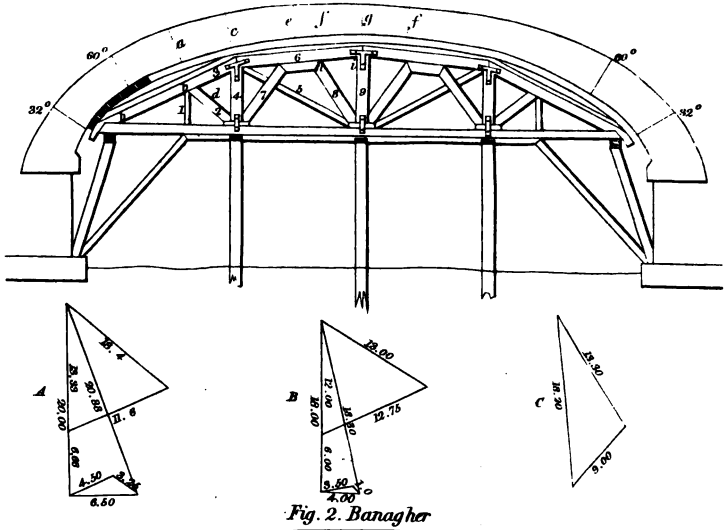


Fig. 2. Banagher

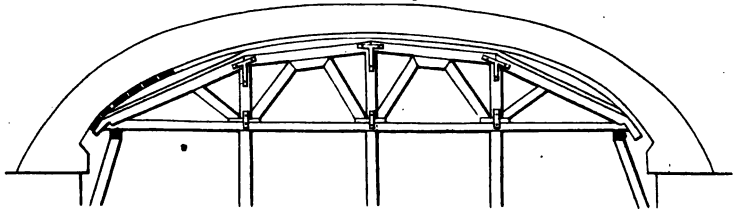


Fig. 3. Donnybrook

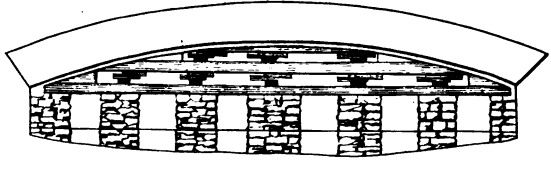
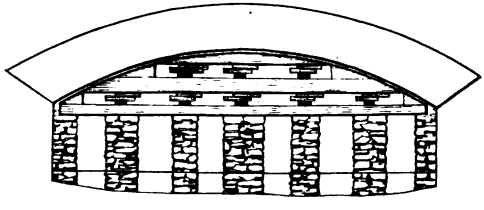


Fig. 4. Aqueduct at Monasterevan



Scale 20 Feet to 1 Inch

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FORSYTH

Fig. 1.

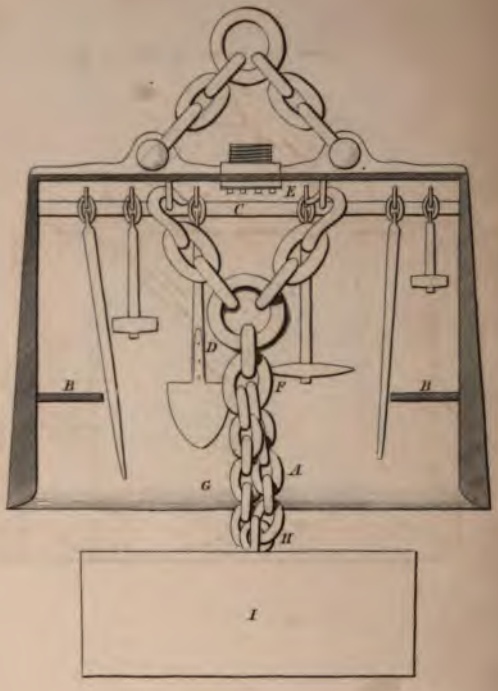
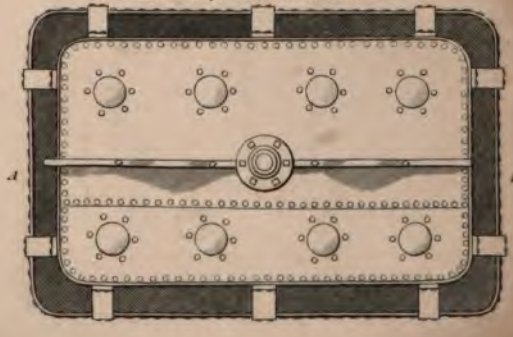


Fig. 4.
Plan of Top, the Chains removed



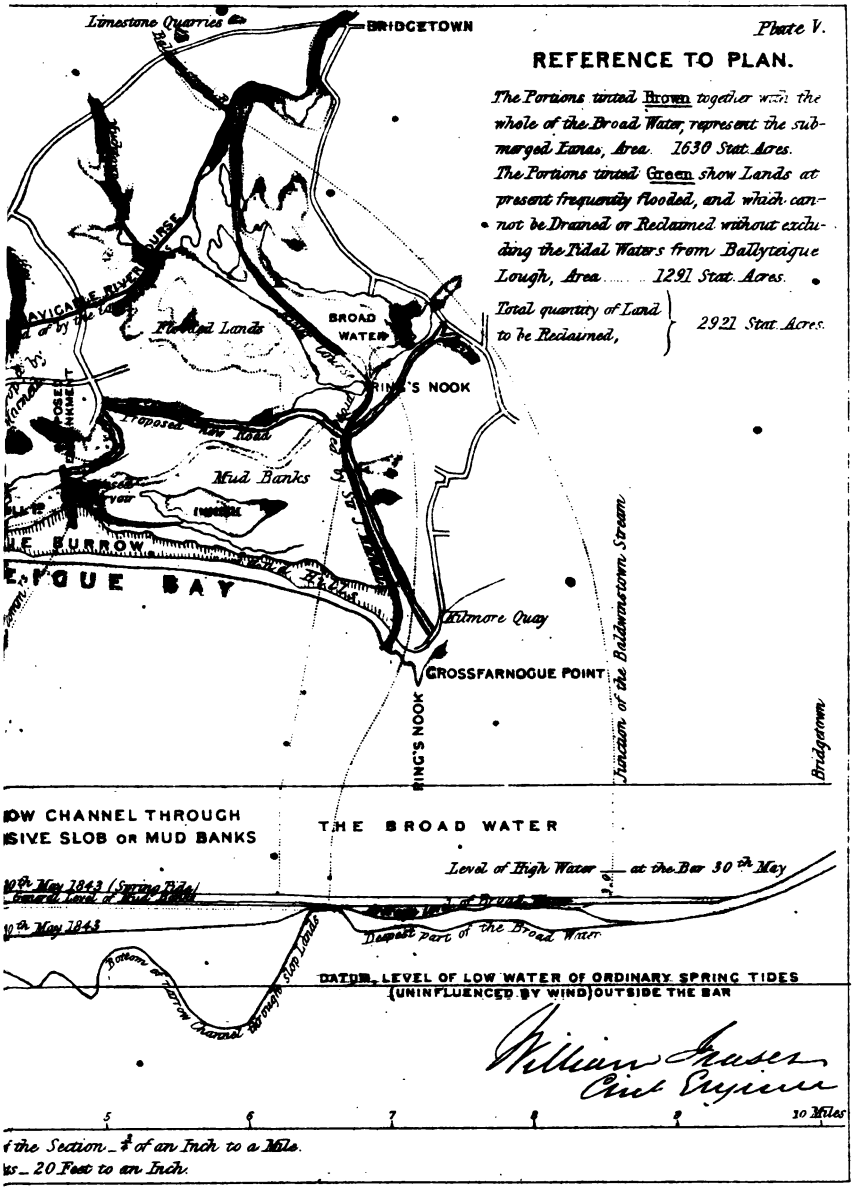


Plate V.
REFERENCE TO PLAN.
The Portions tinted Brown together with the whole of the Broad Water, represent the submerged Lands, Area 1630 Stat. Acres.
The Portions tinted Green show Lands at present frequently flooded, and which cannot be Drained or Reclaimed without excluding the Tidal Waters from Ballyteigue Lough, Area 1291 Stat. Acres.
Total quantity of Land to be Reclaimed, 2921 Stat. Acres.
Limestone Quarries
BRIDGETOWN
BROAD WATER
Flooded Lands
Proposed New Road
Mud Banks
Tilmore Quay
CROSSFARNOGUE POINT
Junction of the Baldwinstown Stream
Bridgetown
THE BROAD WATER
Level of High Water at the Bar 30th May
Deepest Part of the Broad Water
DATUM, LEVEL OF LOW WATER OF ORDINARY SPRING TIDES
(UNINFLUENCED BY WIND) OUTSIDE THE BAR
William Fraser
Civil Engineer
5
6
7
8
9
10 Miles
of the Section - 1/4 of an Inch to a Mile.
ns - 20 Feet to an Inch.

MAC MAHON ON CENTRES.

Fig. 1. Athlone

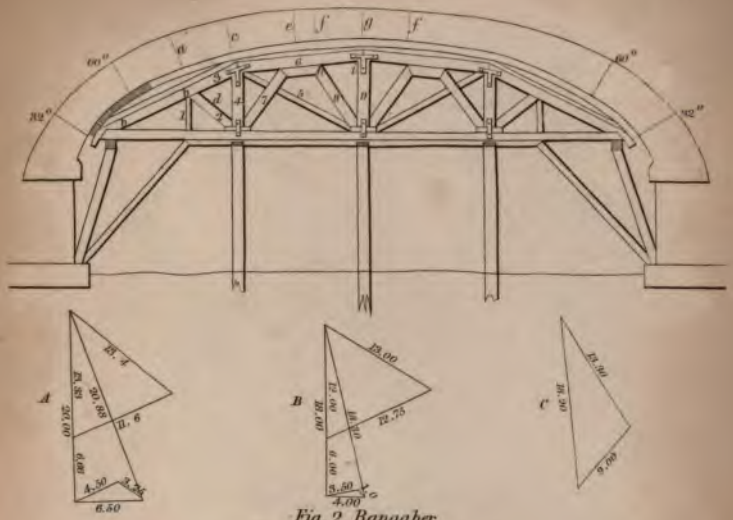


Fig. 2. Banagher

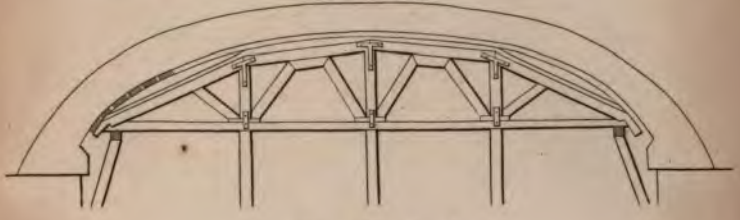


Fig. 3. Donnybrook

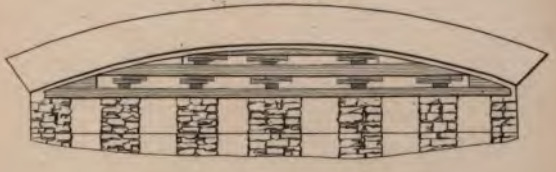
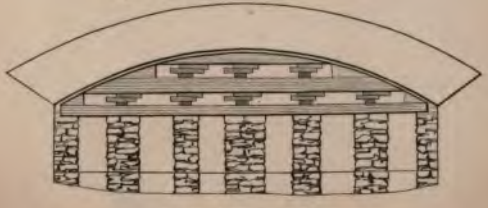


Fig. 4. Aqueduct at Monasterevan



Scale 20 Feet to 1 Inch

Fig. 1. Gen

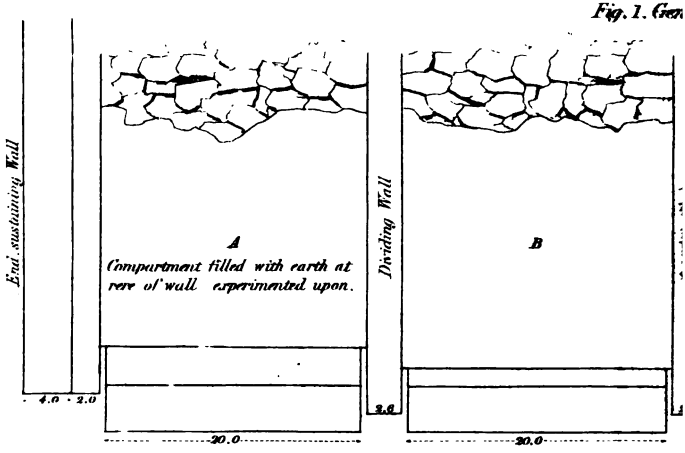


Fig. 2. S

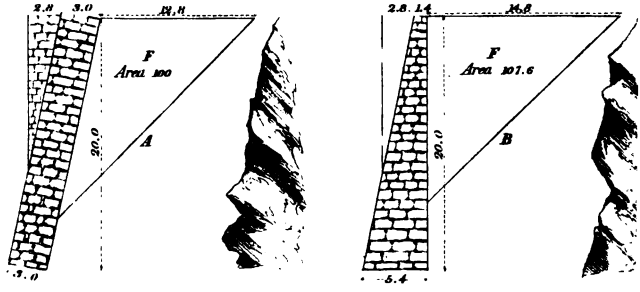
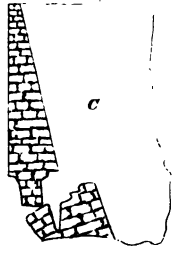
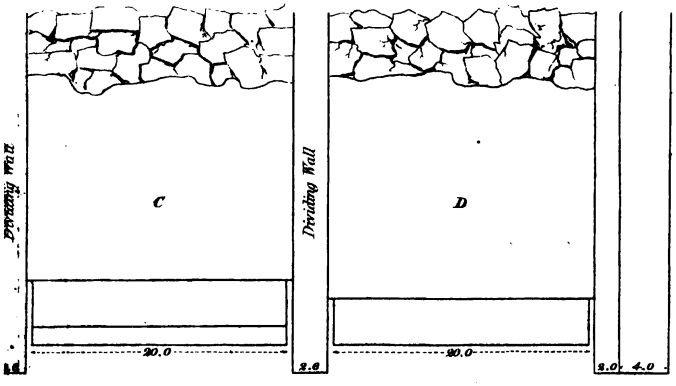


Fig. 3. Wall C, shewing the fracture when falling



ITAL RETAINING WALLS

ral Plan



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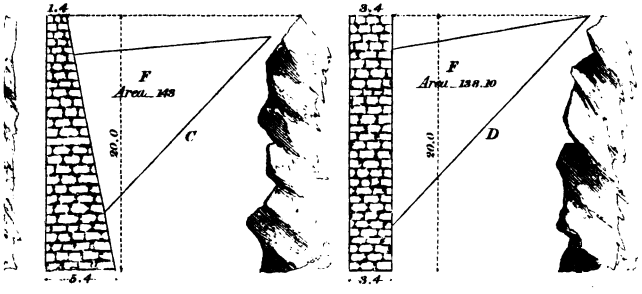
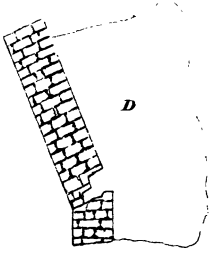


Fig. 4. Wall D. shewing the fracture when filling



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